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RECEIVING WATER QUALITY DATABASE FOR TESTING OF MATHEMATICAL MODELS

by

Wayne C. Huber, David F. MacIntyre and James P. Heaney
Department of Environmental Engineering Sciences
University of Florida
Gainesville, Florida 32611

Cooperative Agreement No. CR 808430

Project Officer

Thomas O. Barnwell, Jr.
Technology Development and Applications Branch
Environmental Research Laboratory
Athens, Georgia 30613

ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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Many mathematical models exist for simulation of quantity and quality parameters of receiving waters. Such models are frequently used in the evaluation of effects on receiving waters of pollution control alternatives such as advanced waste treatment and nonpoint source runoff abatement practices. Data for testing of such models, however, are hard to obtain.

This project has assembled detailed data sets, sufficient for model calibration and verification, for seven sites: Otter Creek, Vermont; Winooski River, Vermont; Chattahoochee River, Georgia; Lower Fox River, Wisconsin; Lake Okeechobee, Florida; Lake Jackson, Florida; Potomac Estuary, Maryland and Virginia. The data are contained in this, on magnetic tape and in addenda. They include physical data (e.g., reach lengths, cross sections), hydrologic and hydraulic data; inflows and outflows, pollutant loads, and in-stream concentrations.

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FOREWORD

As environmental controls become more costly to implement and the penalties of judgment errors become more severe, environmental quality management requires more efficient analytical tools based on greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management or engineering tools to help pollution control officials achieve water quality goals through watershed management.

Complex mathematical models are increasingly used in studies of the movement, transformation and impact of pollutants in rivers and streams, but data for testing these models are hard to obtain. In recognition of this problem, detailed test data for seven receiving water locations have been assembled, sufficient for calibration and verification of models of streams, lakes and estuaries.

William T. Donaldson
Acting Director
Environmental Research Laboratory
Athens, Georgia

ABSTRACT

Many mathematical models exist for simulation of quantity and quality parameters of receiving waters. Such models are frequently used in the evaluation of effects on receiving waters of pollution control alternatives such as advanced waste treatment and non-point source runoff abatement practices. However, data for testing of such models are hard to obtain.

This project has assembled detailed data sets, sufficient for model calibration and verification, for the seven sites listed below:

Rivers
- Otter Creek, Vermont
- Winooski River, Vermont
- Chattahoochee River, Georgia
- Lower Fox River, Wisconsin

Lakes
- Lake Okeechobee, Florida
- Lake Jackson, Florida

Estuary
- Potomac Estuary, Maryland and Virginia

The data are contained in this report, on magnetic tapes and in addenda. They include: physical data (e.g., reach lengths, cross sections), hydrologic and hydraulic data; inflows and outflows, pollutant loads, and in-stream concentrations.

This report was submitted in fulfillment of Cooperative Agreement No. CR-808430 by the University of Florida under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period September 2, 1980 to September 9, 1983, and work was completed as of September 9, 1983.

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Lake Okeechobee, Florida

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SECTION 1

INTRODUCTION AND SUMMARY

1-1. OBJECTIVES

The nation's receiving waters supply water for man and nature, permit recreation and commerce, and drain surplus water and wastes. Many millions of dollars are spent annually to maintain, and in some cases, restore their integrity as healthy water bodies. Planning for such expenditures of necessity should use the most advanced technology available, which in this case usually includes sophisticated mathematical models of physical, chemical and biological processes within the receiving water. Properly formulated and operated models, when coupled with appropriate data for calibration and verification, are tools of tremendous importance as aids in decision making for maintenance of receiving water quality. For example, models can aid in the evaluation of effects on receiving waters of advanced waste treatment and non-point source runoff controls.

Many such models exist (e.g., Huber and Heaney, 1982, Hinson and Basta, 1982, EPA, 1982); this project focuses upon the need for data for proper validation of mathematical representations of actual receiving water processes as well as for calibration (parameter adjustment) and verification (a check on previous parameter adjustments using new data). The overall objective is thus to establish a receiving water quality database suitable for model testing through use of existing efforts at database construction by universities, public agencies and other groups. The results are documented in this report, with most of the data points available on magnetic tapes.

To meet this objective, data have been assembled for the following locations:

Streams/Rivers
- Otter Creek, Vermont
- Winooski River, Vermont
- Chattahoochee River, Georgia
- Lower Fox River, Wisconsin

Lakes
- Lake Okeechobee, Florida
- Lake Jackson, Florida

Estuary
- Potomac Estuary, Maryland and Virginia

Only these seven locations are described in this study in order to provide thorough documentation, as opposed to a more sketchy description of more sites.

The remainder of this section discusses characteristics of the assembled database and methodology of the search for data, and summarizes the attributes of the seven sites listed above.

1-2. DATA TYPES

1-2-1. Purposes

The primary purpose of the receiving water quality database is for model testing and evaluation. However, by its very nature, the database may also serve to characterize the various receiving waters that are included in its formulation. Hence, the multi-purpose nature of the data must be remembered.

"Data" is an ambiguous word because it encompasses a large spectrum of relevant information. Some types are identified below.

1-2-2. Hydrologic and Hydraulic Data

These data may include rainfall and other hydrologic parameters measured in space and time over the tributary basin, particularly for smaller basins. When the receiving water is a larger stream or river, or if storm event data are not under consideration, then measurement of upstream and other boundary conditions may suffice. Within the receiving water, flows and stages are required as a function of time and space. This translates to a tabulation of data from gaging stations within the water body.

Of course, related physical data include hydrologic parameters for the drainage basin, if appropriate, and such items as cross section tabulations, roughness, slope, geometry and other hydrographic information about the receiving water. The nature of such data depends upon whether streams/rivers, estuaries/bays or lakes are being documented. The essential point is that water quality models either simulate quantity as well or require quantity data as input. In either case, groups of the above data are included as part of the database.

1-2-3. Water Quality Data

Measured concentrations of chemical and biological parameters constitute the heart of the database. These are presented as a function of space and time within the receiving water body, e.g., longitudinally along a stream at different times, and for inflows to the receiving water. Many different water quality parameters may be simulated with the more complex of current models, but historically DO and its relationship with

BOD, nitrogen and other oxygen demanding constituents have been the most important. For instance, DO standards are incorporated into the water quality legislation of almost every state. Recently, however, many new parameters have become important, especially toxic metals and organic compounds and are presented where available. Almost all of these water quality data assembled as part of this project have been computerized and are presented on magnetic tapes.

1-2-4. Related Water Quality Parameters

While the original Streeter-Phelps model had only two parameters, i.e., K_1 and K_2, the most complex of today's computer models include literally dozens of rate constants and source-sink terms. Although surveys of numerical values for such parameters exist (e.g., Zison et al., 1978), it is fair to say that such models have generally outstripped their database. All such information that accompanies the data is reported. In addition, detention times, stratification, turbulence, other sources and sinks, etc., all influence concentration data and are reported to the extent that they are documented.

1-2-5. Temporal Characteristics

Models exist to analyze both steady state inputs, as from a waste treatment plant, and transient inputs, as from non-point source runoff during a storm event. Typically, both types of data (i.e., before, during, and after a storm) are needed to evaluate transient models. That is, some parameters are calibrated using the base flow conditions, and others using the sotrm hydrograph.

In searching for data as part of this project, it has been observed that most well-documented studies have focused on steady-state conditions. Typical sampling programs have involved long-term studies during which samples are collected at intervals of a few days to a few weeks, or else brief, intensive surveys lasting a few hours to a few days. Transients imposed upon the receiving water (e.g., by a rainfall event) are usually incidental and often a modeling inconvenience. Within this project, detailed information on short-term water quality transients is available only as incidental parts of the data for Otter Creek, Lake Jackson and the Potomac Estuary.

1-3. DATA SOURCES

Many different groups were approached for data during the course of the project, of which most possessed candidate data sets. Federal agencies contacted include:

Environmental Protection Agency
- Athens, Georgia
- Atlanta, Georgia
- Cincinnati, Ohio

Edison, New Jersey
Corvallis, Oregon
Seattle, Washington
Washington, D.C.
Annapolis, Maryland

U.S. Geological Survey
Reston, Virginia
Bay St. Louis, Mississippi
Tallahassee, Florida
Tampa, Florida
Menlo Park, California
Portland, Oregon
Denver, Colorado

Corps of Engineers
Waterways Experiment Station, Vicksburg, Mississippi
Hydrologic Engineering Center, Davis, California

Other contacts included several state "environmental regulation" departments, river basin commissions, councils of governments, water management districts, universities, consultants, municipalities and the National Council for Air and Stream Improvement. Not all of these groups possessed complete data sets, but many contributed information to add to other data sets.

The object of the search was to find only a few good, well-documented sites that are suitable for the objectives stated earlier rather than an attempt to document several sites in a less detailed manner. Several additional locations which offer good data are described in Section 9. In a few instances, good data sets are not included as part of the results from this project simply because they were encountered too late to provide time for processing them.

1-4. SITE CHARACTERISTICS: SUMMARY

1-4-1. Introduction

The seven sites included in the data base are discussed briefly below, and their characteristics are summarized in Table 1-1 (rivers), Table 1-2 (lakes) and Table 1-3 (Potomac Estuary). Site locations are shown on Figure 1-1. References pertaining to the individual site are not included in the paragraphs below and may be found in the appropriate chapter for each site.

In general, suitable data for rivers and streams are plentiful; these data were the easiest to obtain for the project, and several alternative data locations exist. The four selected river sites were among the best documented of those encountered during the project.

TABLE 1-1. CHARACTERISTICS OF THE SELECTED RIVER LOCATIONS.

River Name	Length of Study Section (miles)	7Q10 Flow (cfs)	No. of Point Sources	Parameters Measured	Approximate Frequency & Duration of Measurements	No. of Stations	No. of Independent Data Sets	No. of Tributaries In Study Area	Other Data****
Otter Creek	21	79	5	Temp, D.O., BOD_5, NO_3-NO_2-N, NH_3-N, TKN.	4 hourly (for 3 days)	22	2	3	Point Source BOD, NO_3-NO_2, NH_3, TKN loads. Steam bed profile. Daily precipitation + max & min air temps.
Upper Winooski River	7.6	60	2	Temp, D.O., BOD_5, NO_3-NO_2-N, NH_3-N, TKN (Ortho-P Total-P, Chlorophyll a, one data set only).	4 hourly (for 2-3 days)	12	2	4	Point source BOD, NO_3-NO_2-N, NH_3-N TKN loads. Stream bed profile. Daily precipitation + max min air temps.
Chattahoochee River	43	~980*	7	Temp, D.O., BOD_5, pH, Total-N, Organic-N, NH_3-N, NO_2-N, Total-P, Ortho-P, Fecal Strep., Trace metals, Suspended solids**	1-9 per day (for 1-4 days)	31	4	16	River bed profile. 41 river cross-sections. 41 Mannings Coeffs. limited land use data.
Lower Fox River	39	950	33	Temp, D.O., BOD_5, Secchi depth, Organic N, NO_3-NO_2-N, Total-P, Soluble-P, % volatile solids***	Daily (for 1 day)	49	9	5	49 mean cross-sectional depths. River bed profile. Point source BOD loads.

* Estimate. Flow is regulated

** Some parameters not measured at all stations.

*** Not all measured in all surveys. Some surveys contain only temp & D.O.

**** Measured flow rates are available for all except the Lower-Fox River, which was estimated. Measured and/or estimated flow velocities are available for all rivers.

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TABLE 1-2. CHARACTERISTICS OF THE SELECTED LAKE LOCATIONS.

	Lake Okeechobee	Lake Jackson
Watershed Area* (sq. miles)	4,600	42.2
Lake Area (sq. miles)	706	6.25**
Mean Depth (feet)	9.2	5.6**
Trophic State	Eutrophic	Mesotrophic
Residence Time (years)	1.0	0.7**
Parameters Measured	Temp, D.O., Specific Conductance, pH, Secchi Depth, Turbidity, Color, Total Susp. Solids, Ortho-P, Total-P, NO_x-N, NO_2-N, NO_3-N, NH_4-N, TKN-NH_4-N, Total N, Total Fe, A-Alkalinity	Temp, pH, alkalinity, turbidity, suspended solids, Secchi Depth, Specific Conductance, Color, NO_3-N, NO_2-N, NH_3-N, Ortho-P, Total-P, Total dissolved P, D.O., (+ some chloride & sulfate)
Approximate Frequency & Duration of Measurements	Biweekly to monthly (for 7 years)	Monthly (4 studies covering 10 years)
Number of Stations	8 & 40	10 (not in same positions for all studies)

* 1 square mile = 640 acres

** These figures are based on a stage of 87 ft-MSL. In recent years the stage level has varied considerably.

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TABLE 1-3. CHARACTERISTICS OF THE SELECTED ESTUARY LOCATION.

	Potomac
Length (miles)	117
Average Flow (cfs)	10,000
Type	Well mixed
Reporting Agencies	EPA, COG, USGS, COE, Consultants
Point Sources	13 POTW's monitored and estimated
Non-Point Sources	CSO's monitored in D.C., others estimated
Parameters	Temp, D.O., Salinity, BOD_5, Nutrients, misc.
Frequency and Duration	1968-1981, Intensive: 1979-80, weekly plus some storm event and diel
No. of Stations	25 EPA, 34 USGS
Other Data	Misc. cross sections, meteorological, navigation, maps, etc.

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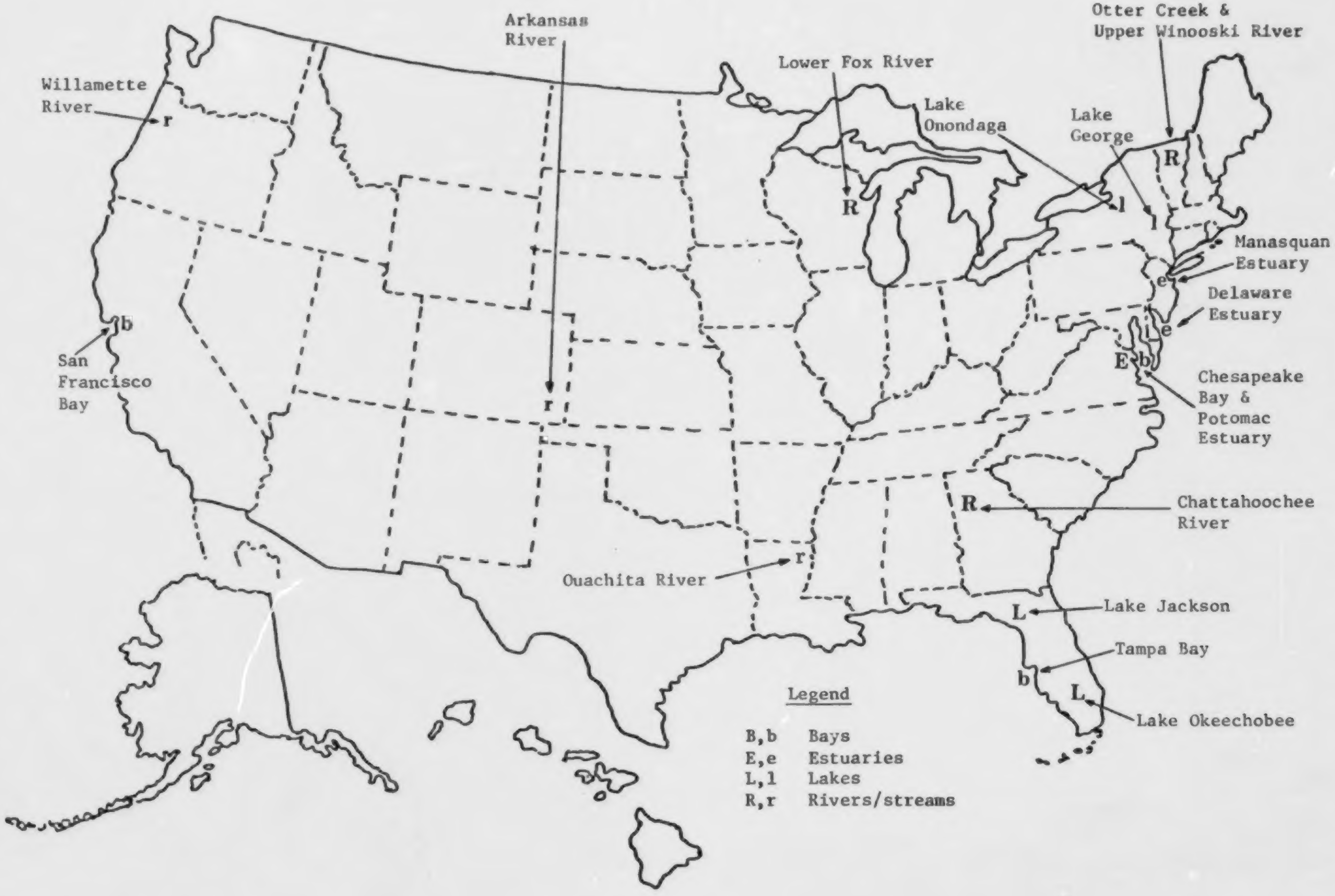
Otter Creek &
Upper Winooski River
Arkansas
River
Lower Fox River
Lake
Onondaga
Lake
George
Willamette
River
r
R
R
l
Manasquan
Estuary
e
Delaware
Estuary
e
b
San
Francisco
Bay
E
b
Chesapeake
Bay &
Potomac
Estuary
r
R
Chattahoochee
River
Ouachita River
r
L
Lake Jackson
Tampa Bay
b
L
Lake Okeechobee
Legend
B,b Bays
E,e Estuaries
L,l Lakes
R,r Rivers/streams

Figure 1-1. Locations of data sites. Upper case letters indicate sites included in the project. Lower case letters indicate additional potential sites discussed in Section 9.

Although lake data themselves are numerous, well-documented comprehensive studies are not. The two selected lake studies were chosen primarily because of their comprehensive nature and proximity to the University of Florida, which made it possible to obtain the necessary ancillary information. Most other comprehensive lake studies (e.g., Lake George in New York) had highly distributed documentation and/or non-computerized data sets.

Sites for estuaries and bays have similar problems to those for lakes. The selected site (the Potomac Estuary) possesses an enormous history of studies and data, and has the advantage of a recent, computerized database. Although the Delaware Estuary also has a long history of water quantity and quality studies, it has not received as much recent attention as the Potomac, and its data are mostly locked up in the STORET files. During the course of this project it was found that documentation of even one estuary of the degree of complexity of the Potomac was a large task; hence, only one estuary site has been included.

1-4-2. Otter Creek, Vermont

Otter Creek is a stream in the Champlain Valley in western Vermont. It is about 100 miles long and empties into Lake Champlain. Intensive surveys during the low flow conditions on August 1-3, 1977 and August 1-3, 1978 were performed as part of a wasteload allocation study by the State of Vermont Agency of Environmental Conservation on a 21 mile segment of the stream.

The 1977 data were used to calibrate Massachusetts' STREAM 7 model, and the model was verified using the 1978 data. This model generates DO, $CBOD_5$, and NBOD profiles. The input parameters and biochemical rate constants used by the Vermont agency are given.

1-4-3. Upper Winooski River, Vermont

The Winooski River flows from Washington County, Vermont westwards through Montpelier to Lake Champlain. It is about 90 miles long and has a drainage area of 1,080 square miles. The study area contains 3.4 miles of the Stevens Branch immediately upstream of its junction with the Winooski River, and 4.2 miles of the Winooski River from just above its junction with the Stevens Branch downstream through Montpelier. This section of the Winooski has two small tributaries in addition to the Stevens Branch.

The studies on this river were also performed as part of a wasteload allocation study by the State of Vermont Agency of Environmental Conservation. Intensive water quality surveys were performed under low flow conditions on August 22-24, 1978 and July 9-11, 1979.

1-4-4. Chattahoochee River, Georgia

The Chattahoochee River flows southwards from the mountains of north Georgia to Lake Seminole on the Georgia-Florida border. The section used in this study is a 43 mile segment from Atlanta downstream to Whitesburg. In addition to effluent from seven sewage treatment plants, this segment also receives runoff from urban and cultivated areas. There are also several small tributaries to the river. There are extensive water quality data available on this segment of the Chattahoochee River, collected by the USGS, State of Georgia and others. The main difficulty is to choose a cohesive data set. Four low flow studies from 1976 and 1977 have been chosen which have been used for model testing by the USGS and others.

1-4-5. Lower Fox River, Wisconsin

The Lower Fox River is 38.9 miles long, and flows from Lake Winnebago to Green Bay. The river is heavily utilized, receiving effluent from 32 sources, including 13 sewage treatment plants. There are five small tributaries and 15 points at which water is withdrawn (mostly for industrial use). The data presented in this report are drawn from a prolonged wasteload allocation study by the Wisconsin Department of Natural Resources. Surveys were conducted on June 20-21, 1972; July 18-19, 1972; August 14-15, 1972; June 12, 1973; July 24-25, 1973; July 26-27, 1975; August 30-31, 1976; July 26-27, 1977.

The QUAL-III model has been calibrated and verified using nine data sets by the Wisconsin DNR. The model coefficients are presented in this report.

1-4-6. Lake Okeechobee, Florida

Lake Okeechobee is situated in south Florida, north of the Everglades. With an area of 706 square miles, it is the second largest freshwater lake in the U.S. after Lake Michigan. The lake is surrounded by a large dike to protect surrounding areas from flooding during a hurricane. All inflows and outflows are controlled as they pass through the dike so that the lake level can be regulated. However, the water budget for the lake is not well determined because of difficulties in calculating the amount of precipitation and interactions with groundwater. The lake is in a eutrophic condition.

Lake water quality has been monitored extensively from 9/73 to 3/80 by the South Florida Water Management District which is responsible for regulation of the lake. Input-output, systems, and complex hydrodynamic models have been applied to Lake Okeechobee. The dynamics of nutrient cycles in the lake have been investigated, and some spatially lumped models for nitrogen and phosphorus have been developed.

1-4-7. Lake Jackson, Florida

Lake Jackson is situated on the outskirts of Tallahassee in northwest Florida. The lake has an area of 4,000 acres and is situated in a watershed of 27,500 acres. It is in a mesotrophic state and in the past has been especially valued for the quality of its game fishing. The lake is largely flat bottomed, and few areas are deeper than 14 feet. There are no exit channels from the lake, so that the only inputs are rainfall and runoff, and the only outlets are evaporation and groundwater recharge. The hydrologic history shows wide fluctuations in the lake level in response to annual rainfall.

The data presented in the report are based on studies by the Florida Game and Fresh Water Fish Commission and Florida State University (FSU) from 6/28/71 to 6/3/74, the Florida Game and Freshwater Fish Commission from 10/74 to 4/76, the Department of Environmental Regulation (DER) and Florida Institute of Technology from 12/76 to 11/77 and a study by DER and FSU from 12/77 to 6/81. Forty-two storm events were also reported, but there are no reports of modelling studies on the lake.

1-4-8. Potomac Estuary, Washington, D.C.

The Potomac Estuary runs 117 miles from Chain Bridge through Washington, D.C. to Chesapeake Bay. The estuary is well mixed vertically so that saline wedge effects rarely occur. Mathematical modelling of the Potomac Estuary was initiated in the 1960's by predecessor agencies to the EPA, and many programs of data collection have been reported. The selected period from between 1979-1981 includes intensive and synoptic studies sponsored by the USGS, EPA and Washington, D.C. Council of Governments. Modelling activity on the Potomac is also extensive.

1-5. DATABASE FORMAT

Site descriptions, maps, pollutant sources, rate constants, etc., are given in this report as much as is possible. Measured receiving water quality data values are presented on magnetic tapes. Modelling data (e.g., for the QUAL-II model) for several sites are also included on the magnetic tapes wherever available. In some instances (e.g., the Fox River) the modelling data also serve to document point and non-point source loads to the receiving water. In a few instances, some useful but bulky information (e.g., stream cross sections) is available as an addendum to this report. All data and their locations (i.e., report, tapes, addendum) are summarized at the end of the chapter for each site.

1-6. SUFFICIENCY OF PROJECT DATA FOR MODEL TESTING

Can the information supplied for the seven sites by this project be used by itself for model testing? Probably not. Considering that most sites are documented with multiple reports of hundreds of pages, it is unrealistic to assume that all the information anyone would need about a particular site could be included in approximately 30 pages of text in this report. Modelers will want to obtain the references listed for a site in order to obtain complete information, although it is intended that the material presented in this project could certainly initiate a modelling study. In addition to the site summaries and references, the primary value of this project is the presentation of the voluminous in-stream data in a machine readable format on magnetic tapes. This should bypass a considerable task of most modelling projects.

1-7. REFERENCES

1. Environmental Protection Agency, "Environmental Modeling Catalogue: Abstracts of Environmental Models," Environmental Protection Agency Information Clearinghouse (PM-211A), Washington, D.C., August 1982.

2. Hinson, M.O. and Basta, D.J., "Analyzing Surface Receiving Water Bodies," in Basta, D.J. and Bower, B.T., (editors), Analyzing Natural Systems: Analysis for Regional Residuals-Environmental Quality Management, Resources for the Future, Johns Hopkins University Press, Baltimore, June 1982.

3. Huber, W.C. and Heaney, J.P., "Analyzing Residuals Generation and Discharge from Urban and Nonurban Land Surfaces," in Basta, D.J. and Bower, B.T., (editors), Analyzing Natural Systems: Analysis for Regional Residuals-Environmental Quality Management, Resources for the Future, Johns Hopkins University Press, Baltimore, June 1982.

4. Zison, S.W., Mills, W.B., Deimer, D. and Chen, C.W., "Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling," EPA-600/3-78-105, Environmental Protection Agency, Athens, GA, December 1978.

SECTION 2

OTTER CREEK

2-1. INTRODUCTION

Otter Creek is situated in the Champlain Valley, Vermont. It begins in the northern part of Bennington County and meanders through the counties of Rutland and Addison, emptying into Lake Champlain at the Town of Ferrisburg (Figure 2-1). The main stream is approximately 161 km (100 mi) long, and has a total drainage area of 2,420 km^2 (936 mi^2). The valley of Otter Creek is generally narrow upstream of Proctor, while the valley section downstream of Proctor is broad and flat.

The information presented in this report section was derived from a wasteload allocation study by the State of Vermont Agency of Environmental Conservation. The study included two intensive water quality surveys of the segment of Otter Creek from Moon Brook in the City of Rutland to Jones Brook near Brandon Village. This 33.8 km (21.0 mi) long segment receives the effluent from five publicly owned treatment works (POTW's), and the assimilative capacity of the creek is exceeded. The surveys from which the reports are drawn took place during low flow conditions in August 1-4, 1977 and August 1-4, 1978.

2-2. SOURCE LITERATURE

Most of the information in this report was drawn from two reports issued by the State of Vermont Agency of Environmental Conservation, both of which were written by Van Benschoten and Clarkson (1979a,b). The first report describes the data collected during two intensive surveys of Otter Creek under low flow conditions on August 1-4, 1977 and August 1-4, 1978, while the second concentrates on efforts to model the creek using these data.

There is also a study on water quality in Otter Creek by Porteous (1977) which was published by the Environmental Protection Agency. The report covers a three week water quality survey during July and August 1976. The water quality data from this earlier survey are not included in this report because the University of Florida could not obtain a timely copy of the data. However, information on channel cross-sections and flow stages is presented.

2-3. RIVER BASIN DESCRIPTION

2-3-1. Study Area

Otter Creek is situated in the Champlain Valley in western Vermont, and is 161 km (100 mi) long. The river section studied in this report is 33.8 km (21.0 mi) long, and runs from Moon Brook in the City of Rutland to Jones Brook near Brandon Village. This section of Otter Creek is shown in Figure 2-1, and the positions of the sampling stations are given in Table 2-1.

2-3-2. Hydrologic Data

Point Inflows--

There are three tributaries flowing into the studied section of Otter Creek. They are East Creek (Otter Creek kilometer 115.9/mile 72.0), Clarendon River (Otter Creek kilometer 113.5/mile 70.5), and Furnace Brook (Otter Creek kilometer 97.0/mile 60.3). The flow data for Otter Creek and its tributaries during the 1977 and 1978 surveys are shown in Table 2-2. The seven consecutive day low flow with a recurrence interval of ten years (7Q10) is 2.24 m^3/s (79 ft^3/sec) at the Center Rutland gage (Van Benschoten and Clarkson, 1979a).

The studied segment of Otter Creek receives the effluent from five publicly owned treatment works. The effluent flow rates from these installations are shown in Table 2-3. The sum of these effluent flows supplied approximately 4% to 5% of the river's flow during the low flow survey periods.

Non-Point Inflows--

The Vermont Agency of Environmental Conservation used the following equation to account for non-point flow:

$$Q_x = Q_0 + q_a A_x \tag{2-1}$$

where Q_x = flow at point x, ft^3/sec,

Q_0 = flow at point x=0 where incremental flow begins, ft^3/sec,

q_a = areal distributed incremental flow, $ft^3 sec^{-1} mi^{-2}$, and

A_x = increase in drainage area from x=0 to point x, mi^2.

The report by Van Benschoten and Clarkson (1979b) breaks the study area down into eight reaches and gives values of A_x for each reach. The positions of the reach boundaries are given in Table 2-4, and information on drainage areas and non-point loads is given in Table 2-5. Van Benschoten and Clarkson used a value of $q_a = 0.586$ cfs/mi^2.

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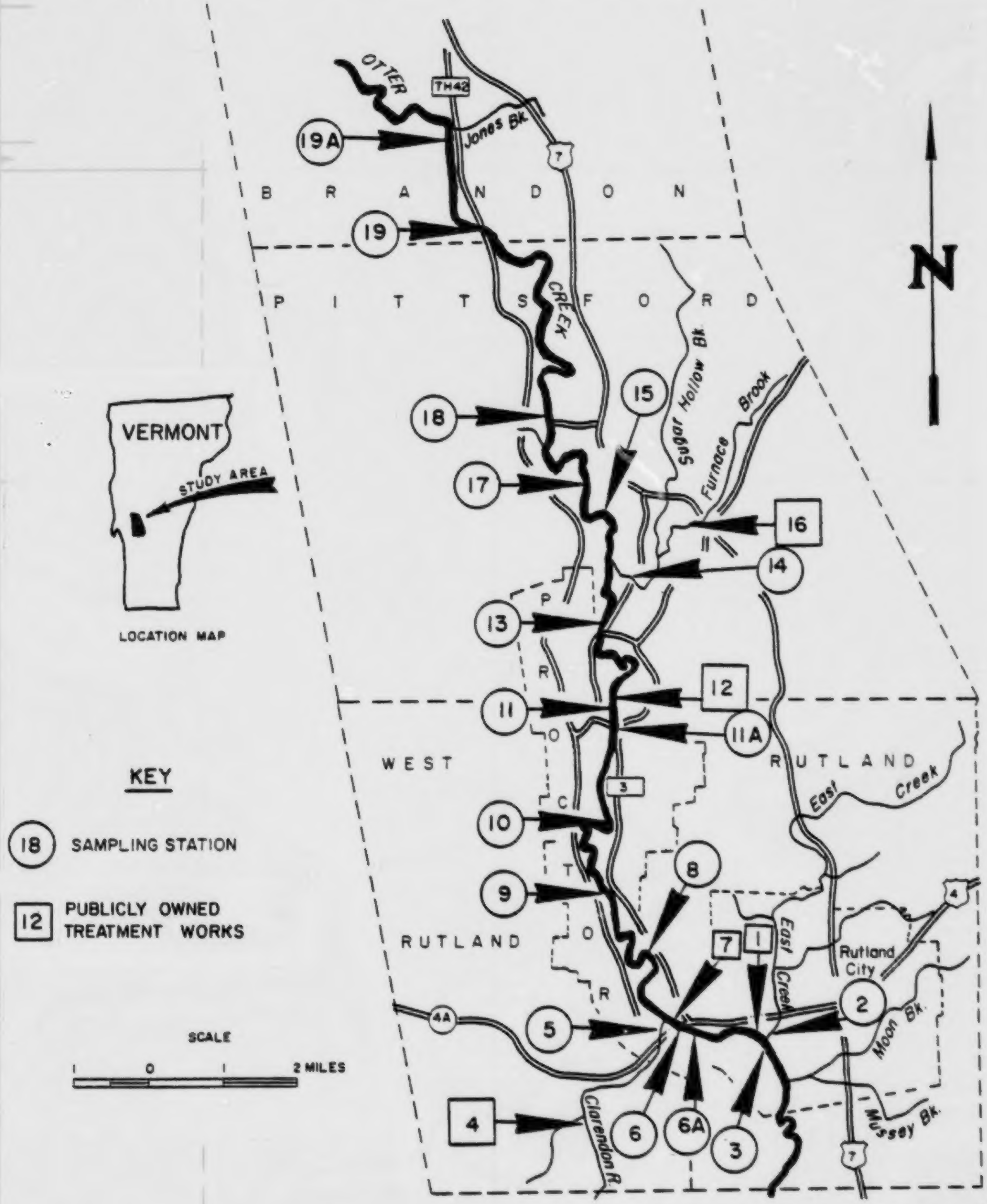
OTTER
TH42
Jones Bk.
7
19A
19
B R A N D O N
P I T T S F O R D
CREEK
Sugar Hollow Bk.
Furnace Brook
15
18
17
16
14
13
12
11
11A
P
R
O
C
T
O
R
WEST RUTLAND
RUTLAND
East Creek
3
10
9
8
7
1
East Creek
Rutland City
4
2
Moon Bk.
4A
5
6
6A
3
4
Clarendon R.
Mussey Bk.
7
N
VERMONT
STUDY AREA
LOCATION MAP
KEY
18 SAMPLING STATION
12 PUBLICLY OWNED TREATMENT WORKS
SCALE
1 0 1 2 MILES

Figure 2-1. Otter Creek study area (after Van Benschoten and Clarkson, 1979a).

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TABLE 2-1. LOCATION OF SAMPLING STATIONS (after Van Benschoten and Clarkson, 1979a)

Station Number	Otter Creek (Mile)	Otter Creek (Km)	Location
3	72.1	116.0	Otter Creek: River Street bridge upstream of East Creek
2	72.0	115.9	East Creek at 0.1 mi (0.15 km): At rear of pump station
1	71.9	115.7	POTW - Rutland City: Discharges to Otter Creek
6A	70.9	114.1	Otter Creek: Railroad bridge upstream of Center Rutland Dam
6	70.7	113.8	Otter Creek: Route 4 bridge
7	70.6	113.6	POTW - Rutland Town: Discharges to Otter Creek
4	70.5	113.5	POTW - West Rutland: Discharges to Clarendon River at 1.8 mi (2.9 km)
5	70.5	113.5	Clarendon River at 0.3 mi (0.5 km): Route 4 bridge
8	69.6	112.0	Otter Creek: First meander downstream of Route 4 bridge
9	67.2	108.1	Otter Creek: 0.2 mi (0.3 km) upstream of old bridge opposite quarry hole on Route 3
10	65.6	105.6	Otter Creek: 0.4 mi (0.6 km) downstream of railroad bridge, near pull off on Route 3
11A	63.7	102.5	Otter Creek: Bridge in Proctor
11	63.4	102.0	Otter Creek: Below dam at rear of Vermont Marble, underneath pipeline
12	63.3	101.9	POTW - Proctor: Discharges to Otter Creek
13	61.7	99.3	Otter Creek: Gorham bridge downstream of Proctor
16	60.3	97.0	POTW - Pittsford: Discharges to Furnace Brook at 2.1 mi (3.4 km)
14	60.3	97.0	Furnace Brook at 0.8 mi (1.3 km): Bridge just upstream of confluence with Otter Creek
15	59.6	95.9	Otter Creek: Railroad bridge near Pittsford
17	58.6	94.3	Otter Creek: Covered bridge upstream of Florence
18	57.1	91.9	Otter Creek: Covered bridge downstream of Florence
19	52.6	84.7	Otter Creek: Bridge #356 near Brandon
19A	51.1	82.2	Otter Creek: Just upstream of Jones Brook

TABLE 2-2. OTTER CREEK AND TRIBUTARY FLOWS (after Van Benschoten and Clarkson, 1979a)

1977

Location	Date 08/01 (ft^3/sec)	 08/02 (ft^3/sec)	 08/03 (ft^3/sec)	Mean (ft^3/sec)	Mean (m^3/sec)
Otter Creek at Center Rutland (USGS gage) [a]	141	212	192	180	5.1
East Creek	-	-	-	34	1.0
Clarendon River [b]	-	9	17	13	0.4
Furnace Brook [b]	-	22	20	21	0.6

1978

Location	Date 08/01 (ft^3/sec)	 08/02 (ft^3/sec)	 08/03 (ft^3/sec)	Mean (ft^3/sec)	Mean (m^3/sec)
Otter Creek at Center Rutland (USGS gage) [a]	170	175	- [c]	172	4.9
East Creek	-	-	-	35	1.0
Clarendon River [b]	21	14	13 [d]	16	0.5
Furnace Brook [b]	20	-	13 [d]	17	0.5

[a] Recorded flows are mean daily flows.
[b] Recorded flows are instantaneous field measurements.
[c] No reliable estimate of flow due to heavy rain and jammed punch block at gage.
[d] Field measurements taken before rain event.

Daily flows for East Creek are not available.

TABLE 2-3. PUBLICLY OWNED TREATMENT WORKS AVERAGE DAILY FLOWS (after Van Benschoten and Clarkson, 1979a)

1977

Station Number	Facility	Date 08/01 (mgd)	08/02 (mgd)	08/03 (mgd)	Mean (mgd)	Mean (ft^3/sec)	Mean (m^3/sec)
1	Rutland City	4.630	4.575	4.520	4.575	7.09	0.200
4	West Rutland	0.097	0.105	0.084	0.0953	0.148	0.00418
7	Rutland Town	0.012	0.019	0.015	0.015	0.024	0.00067
12	Proctor	0.1227	0.1372	0.1262	0.1287	0.200	0.00564
16	Pittsford	0.0343	0.0333	0.0316	0.0331	0.051	0.00145

1978

Station Number	Facility	Date 08/01 (mgd)	08/02 (mgd)	08/03 (mgd)	Mean (mgd)	Mean (ft^3/sec)	Mean (m^3/sec)
1	Rutland City	5.14	5.16	-[a]	5.15	7.98	0.226
4	West Rutland	0.157	0.163	0.166	0.162	0.251	0.00710
7	Rutland Town	0.014	0.019	0.016	0.016	0.025	0.00072
12	Proctor	0.216	0.227	0.229	0.224	0.347	0.00981
16	Pittsford	0.051	0.055	0.072	0.059	0.092	0.0026

[a] Facility bypassed during rainstorm.

TABLE 2-4. OTTER CREEK REACH BOUNDARIES FOR MODELLING (after Van Benschoten and Clarkson, 1979b)

Reach	Otter Creek Mile	Otter Creek Kilometer	Reach Boundaries
	72.1	116.0	River Street bridge in Rutland
1			
	70.9	114.1	Center Rutland Dam
2			
	70.5	113.5	Confluence of Clarendon River with Otter Creek
3			
	67.2	108.1	Water quality sampling station 9
4			
	65.6	105.6	Water quality sampling station 10
5			
	65.6	102.4	Sutherland Falls Dam
6			
	60.3	97.0	Confluence of Furnace Brook with Otter Creek
7			
	58.6	94.3	Covered bridge upstream of Florence
8			
	52.6	84.6	Bridge #347 near Brandon

TABLE 2-5. NON-POINT INFLOW INFORMATION (after Van Benschoten and Clarkson, 1979b)

Reach*	Upstream of Study Area	1	2	3	4	5	6	7	8
Reach End Drainage Area (mi^2)	246	307	308	364	367	371	378	431	443
Tributary Drainage Area (mi^2)	–	58	–	49	–	–	–	50	–
Areal Flow D.O.** (mg/l)	–	1	1	1	1	1	1	1	1
Areal Flow CBOD$_5$** (mg/l)	–	0	0	0	0	0	0	4	0
Areal Flow NBOD$_u$ (lbs day^{-1} mi^{-1})	–	0	0	0	0	0	0	125	0

*Reaches defined in Table 2-4

**Areal Flow loads based on estimates and model calibration, not-measured.

2-3-3. Hydraulic Data

River Cross-Sections--

Numerous cross-sections for Otter Creek have been obtained from Porteous (1977), and they are presented in an addendum to this report.

Rating Curves--

Broad scale rating curves for Otter Creek are not available, but some information on stages and flow rates at the measured cross-sections are abstracted from Porteous (1977) and presented in an addendum.

Stream Slope--

Except for the Sutherland Falls Dam and the stream section from Ripley Dam to Center Rutland Dam, Otter Creek has an average slope of approximately 2.37×10^{-4} (1.25 ft/mi). The streambed profile is shown in Figure 2-3.

Average Flow Velocities--

The average flow velocities during the intensive surveys were not measured directly, but were calculated by extrapolation from previous EPA flow rate and time of travel studies (see Section 2-3-5). The expected values of time of travel and average velocity for five river reaches are given in Table 2-6.

During the 1977 intensive survey, the Vermont State Department of Water Resources conducted some limited time of travel studies in order to verify the validity of using extrapolations from the EPA data. These data are presented in Table 2-7, and a comparison of the extrapolated 1977 results and measured values is given in Figure 2-2.

When examining the average flow velocities, it is important to consider the effect of the three dams on this section of Otter Creek: Ripley Dam (river kilometer 116.0/mile 72.1), Center Rutland Dam (river kilometer 114.1/mile 70.9), and Sutherland Falls Dam (river kilometer 102.4/mile 63.6). The reservoir storage behind the dams is kept constant so that the volumetric flow rate into any reservoir equals the volumetric flow rate immediately downstream of the dam.

2-3-4. Climatological Data

Precipitation--

During the 1977 and 1978 surveys generally dry conditions prevailed. However, during the 1978 survey there was an intense thunderstorm from approximately 5:45 p.m. to 8:00 p.m. on August 3. Unfortunately, hourly precipitation values are not available, and the daily precipitation values were measured at 6:00 p.m. Consequently the precipitation from the thunderstorm on the evening of August 3 appears as daily precipitation for August 4. The daily precipitation values during the 1977 and 1978 surveys are shown in Table 2-8.

Pan Evaporation--

Although not measured as part of the study, daily pan evaporation values for nearby locations are available from the monthly "Climatological Data" published by the National Weather Service.

TABLE 2-6. TIMES OF TRAVEL AND AVERAGE VELOCITIES EXTRAPOLATED FROM EPA DATA (Porteous, 1977)

1977, Flow Rate = 5.1 m^3/sec (180 ft^3/sec)

From			To			Expected Time of	Expected Average Velocity	
Station	Mile	Km	Station	Mile	Km	Travel(hrs)	ft/sec	m/s
-	75.8	122.0	USGS gage	70.8	113.9	30.5	0.24	0.07
USGS gage	70.8	113.9	11A	63.7	102.5	31.5	0.33	0.10
11A	63.7	102.5	17	58.6	94.3	9.1	0.82	0.25
17	58.6	94.3	18	57.1	91.9	3.5	0.63	0.19
18	57.1	91.9	19	52.6	84.7	11.0	0.60	0.18

1978, Flow Rate = 4.9 m^3/sec (172 ft^3/sec)

From			To			Expected Time of	Expected Average Velocity	
Station	Mile	km	Station	Mile	Km	Travel(hrs)	ft/sec	m/s
-	75.8	122.0	USGS gage	70.8	113.9	32.0	0.23	0.07
USGS gage	70.8	113.9	11A	63.7	102.5	32.5	0.32	0.10
11A	63.7	102.5	17	58.6	94.3	9.2	0.81	0.25
17	58.6	94.3	18	57.1	91.9	3.6	0.61	0.19
18	57.1	91.9	19	52.6	84.7	11.2	0.59	0.18

TABLE 2-7. TIMES OF TRAVEL AND AVERAGE VELOCITIES MEASURED IN 1977 BY VERMONT DEPARTMENT OF WATER RESOURCES (after Van Benschoten and Clarkson, January 1979a)

From			To			Time of	Average Velocity	
Station	Mile	Km	Station	Mile	Km	Travel(hrs)	ft/sec	m/s
1	71.9	115.7	10	65.6	105.6	26.2	0.35	0.11
15	59.6	95.9	17	58.6	94.3	1.6	0.92	0.28
17	58.6	94.3	18	57.1	91.9	2.9	0.76	0.23

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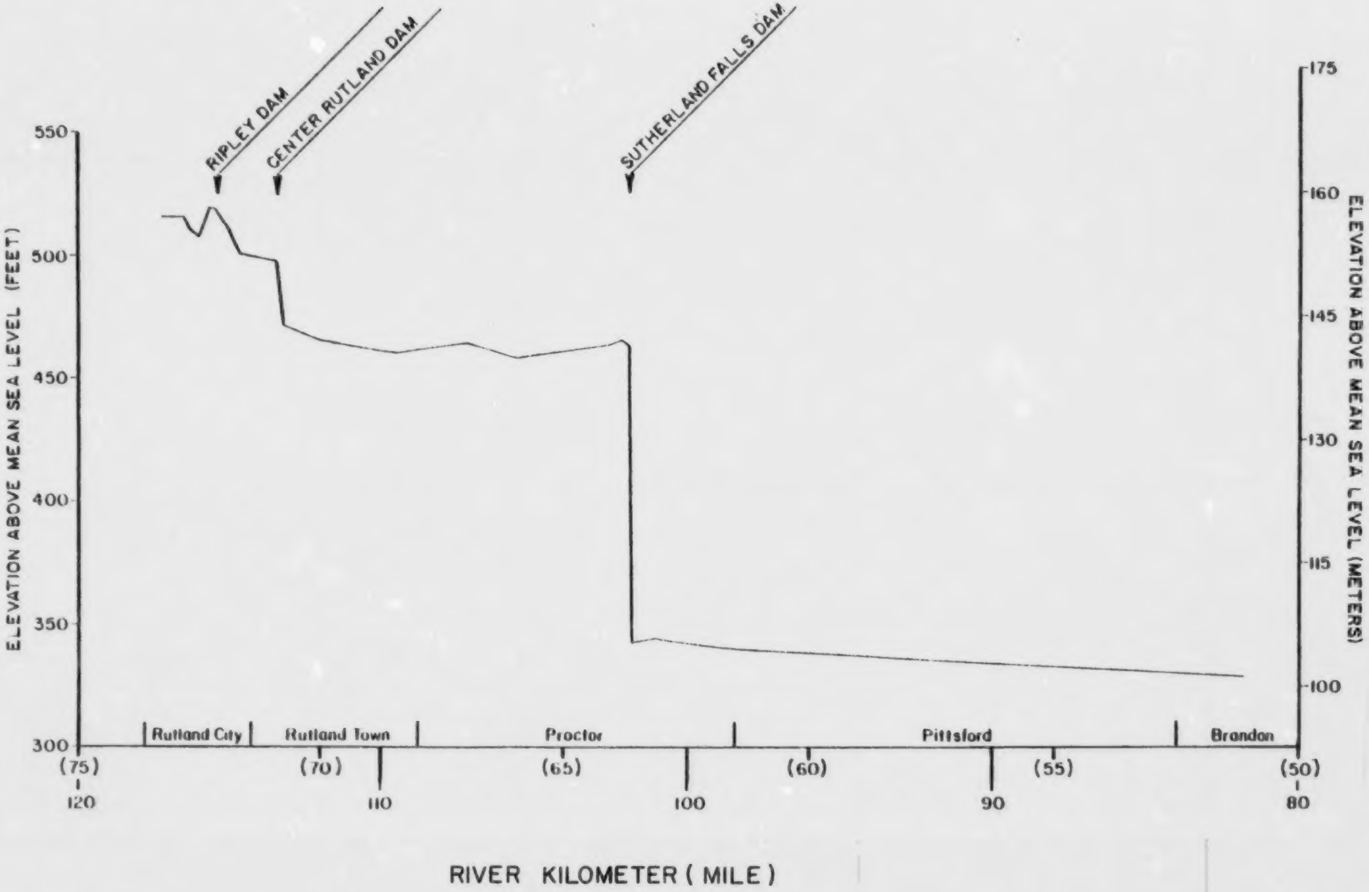

Figure 2-2. Streambed profile of Otter Creek (after Van Benschoten and Clarkson, 1979a).

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(4-76)

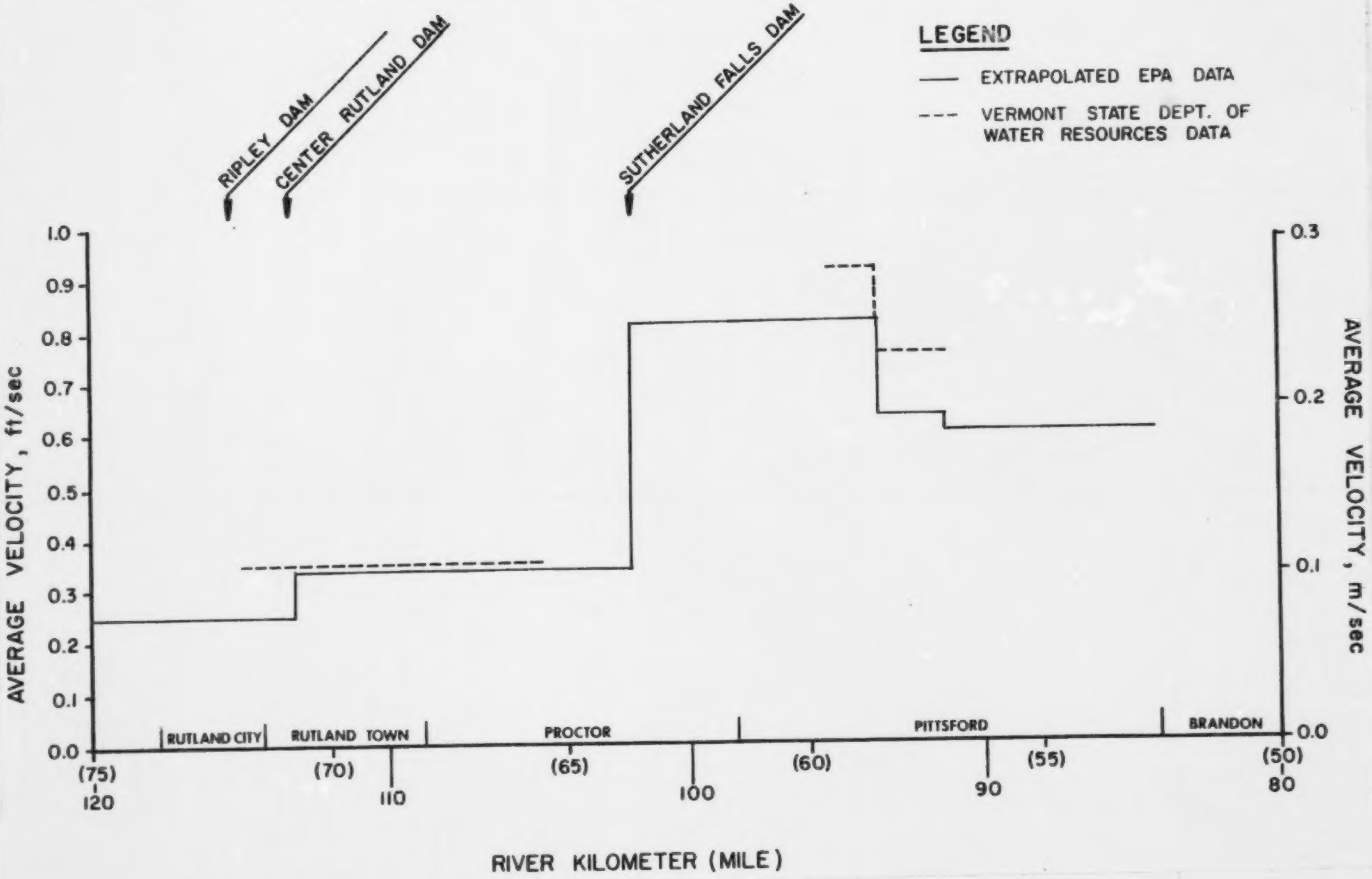

Figure 2-3. Average flow velocities for 1977 from extrapolated EPA data and from time of travel measurements by Vermont State Department of Water Resources.

Ambient Temperatures--

During the 1977 and 1978 surveys, the prevailing temperatures were higher than average for the season. The maximum and minimum daily air temperatures are shown in Table 2-9.

TABLE 2-8. DAILY PRECIPITATION (RUTLAND, VERMONT)
(after Van Benschoten and Clarkson, 1979a)

Date	Rainfall (inches)	Rainfall (centimeters)	Date	Rainfall (inches)	Rainfall (centimeters)
770801	0	0	780801	0.16	0.41
770802	Trace	Trace	780802	Trace	Trace
770803	0	0	780803	0	0
770804	0	0	780804	1.44	3.66

TABLE 2-9. MAXIMUM AND MINIMUM DAILY AIR TEMPERATURES (RUTLAND, VERMONT)
(after Van Benschoten and Clarkson, 1979a)

Date	Max. Temp. (°F)	Max. Temp. (°C)	Min. Temp. (°F)	Min. Temp. (°C)	Date	Max. Temp. (°F)	Max. Temp. (°C)	Min. Temp. (°F)	Min. Temp. (°C)
770801	82	27.8	64	17.8	780801	70	21.1	57	13.9
770802	82	27.8	60	15.6	780802	85	29.4	56	13.3
770803	82	27.8	65	18.3	780803	87	30.6	66	18.9
770804	87	30.6	61	16.1	780704	78	25.6	65	18.3

2-3-5. Sampling Techniques

Flow Rates--

The mean daily flows of Otter Creek were obtained from a U.S. Geological Survey gaging station located just below the Center Rutland Dam at river kilometer 113.9 (mile 70.8). Unfortunately, during the 1978 survey, the punch block at the gaging station was jammed. The flows for 1978, therefore, are estimates based on instantaneous readings, rainfall, operation records from impoundments, comparisons of hydrographs from similar basins, and a comparison from the Middlebury USGS gage further downstream at river kilometer 42.8 (mile 26.6).

The tributaries to Otter Creek were gaged using a Marsh-McBurney model 201 portable water current meter. Depending on stream depth, velocities were measured at either the six-tenths depth or the eight-tenths and two-tenths depths (Carter and Davidian, 1978).

Flow Velocities--

The flow velocities in Otter Creek were not measured directly during the intensive surveys, but were calculated using extrapolated time of travel and flow data. The EPA had conducted time of travel studies using Rhodamine WT dye and a flow-through fluorometer. The river was divided into five reaches, and for each reach the travel time was defined as the time from releasing dye at the upstream end of the reach to the time the peak dye concentration arrived at the downstream end of the reach. The times of travel were measured at flow rates varying from 12.7 m^3/s (450 ft^3/sec) to 31.1 m^3/s (1100 ft^3/sec), with two or three values for each reach. The flow rates, Q, and the times of travel, t, were assumed to follow the relationship

$$\left[\frac{Q_1}{Q_2}\right]^y = \frac{t_2}{t_1} \qquad (2-2)$$

where the parameter y was obtained from graphical analysis of the data. The expected values of time of travel at the low flow rates encountered during the intensive surveys were derived using this formula. The average velocities were then calculated by dividing the reach length by the expected time of travel of travel.

During the 1977 intensive survey, the State of Vermont Department of Water Resources conducted a limited time of travel survey to confirm the validity of using the values extrapolated from EPA data. A comparison of the measured and extrapolated values is presented in Section 2-3-3.

Precipitation and Daily Air Temperatures--

The daily precipitation and maximum and minimum daily air temperatures were measured at the Rutland Weather Station. Unfortunately, hourly precipitation measurements are not made at this station. Information on daily precipitation and air temperatures was taken from:

> National Oceanic and Atmospheric Administration,
> Climatological Data, New England.
> Volume 89, No. 8, August 1977.
> Volume 90, No. 8, August 1978.

2-4. RIVER QUALITY DESCRIPTION

2-4-1. Major Pollution Sources

Point Sources--

The major source of pollution to this section of Otter Creek is the effluent from five publicly owned treatment works. The positions of the POTW's are given in Table 2-1 and Figure 2-1. The average daily flow rates from the POTW's are given in Table 2-3, and the average effluent quality measurements are given in Table 2-10.

It should be noted that the West Rutland POTW drains into the Clarendon River and the Pittsford POTW drains into Furnace Brook. The average water quality measurements of the tributaries close to their junctions with Otter Creek are given in Table 2-11. Their flow rates were presented in Table 2-1.

The mean data values presented in Tables 2-9 and 2-10 were derived from sample readings taken every four to five hours during the intensive surveys. The values given for 1978 in these tables do not include the three readings taken at each station after the rain storm. The detailed values and times of measurement are contained in the computer data set by station number.

Non-Point Sources--

Estimated non-point loads are given in Table 2-5. These estimates are based on calibration data for the STREAM 7 model, not on measurements. The non-point loads were found to be negligible for all reaches except reach 7, from river kilometer 97.0 (60.3 mi) to river kilometer 94.3 (58.6 mi). This river reach shows a rise in concentration of CBOD and NBOD that is not fully accounted for by point sources, so that non-point loading is suspected (Van Benschoten and Clarkson, 1979b). However, visual inspection of the reach and its watershed showed that while there might be some non-point loading from barnyard runoff, there was no obvious source for the amount of non-point loading indicated by the model.

2-4-2. Biochemical Data

Mean Data Values--

The mean values of the biochemical parameters measured at each station are presented in Tables 2-11 and 2-12, and the profiles of the mean parameter values are shown in Figures 2-4 and 2-5. It should be noted that the mean values for 1978 do not include those measurements taken after the beginning of the rain storm on the last day of the intensive survey.

Biochemical Rate Constants--

The Vermont State Department of Water Resources calculated the ultimate BOD loads from POTW's using the values of the carbonaceous deoxygenation rate constant, K_1, given in Table 2-13.

The STREAM 7 water quality model was originally developed in a report by Quirk, Lawler and Matusky Engineers (1971) to the Massachusetts Water Resources Commission, and an updated users manual was written for the Commission by Resource Analysis Inc. (1978). The Vermont State Department of Water Resources applied the STREAM 7 model to Otter Creek. In order to calibrate the instream biochemical rate constant inputs for the model, they divided the surveyed section of Otter Creek into eight reaches, assigning a value of each rate constant in each reach. The reach positions

TABLE 2-10. MEAN EFFLUENT QUALITY DATA VALUES FROM PUBLICLY OWNED TREATMENT WORKS (after Van Benschoten and Clarkson, 1979a)

1977

Station Number	Facility	BOD_5 (mg/l)	NO_3-NO_2-N (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
1	Rutland City	100	0.03	10.4	20
4	West Rutland	25	8.3	6.8	16
7	Rutland Town	220	0.09	24	40
12	Proctor	170	0.04	17	34
16	Pittsford	36	0.02	22	32

1978

Station Number	Facility	BOD_5 (mg/l)	NO_3-NO_2-N (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
1	Rutland City	90	0.52	8.3	15
4	West Rutland	14	0.07	15	19
7	Rutland Town	206	0.18	25	39
12	Proctor	166	0.07	16	27
16	Pittsford	24	0.20	16	23

TABLE 2-11. MEAN WATER QUALITY MEASUREMENTS FROM TRIBUTARIES; MEASURED NEAR TO JUNCTIONS WITH OTTER CREEK (after Van Benschoten and Clarkson, 1979a)

1977

Station Number	Tributary	Temp. (°C)	D.O. (mg/l)	BOD_5 (mg/l)	NO_3-NO_2-N (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
2	East Creek	19.4	8.5	1.0	0.26	0.04	0.33
5	Clarendon River	18.9	8.4	1.2	0.37	0.04	0.32
14	Furnace Brook	18.3	8.8	0.9	0.37	0.05	0.30

1978

Station Number	Tributary	Temp. (°C)	D.O. (mg/l)	BOD_5 (mg/l)	NO_3-NO_2-N (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
2	East Creek	19.2	9.1	0.8	0.26	0.05	0.32
5	Clarendon River	18.4	8.8	1.4	0.23	0.08	0.39
14	Furnace Brook	16.7	9.3	0.4	0.40	0.04	0.22

TABLE 2-12. MEAN WATER QUALITY DATA VALUES MEASURED IN OTTER CREEK (after Van Benschoten and Clarkson, 1979a)

1977

Station Number	River Mile	River Kilometer	Temp. (°C)	D.O. (mg/1)	BOD_5 (mg/1)	NO_3-NO_2-N (mg/1)	NH_3-N (mg/1)	TKN (mg/1)
3	72.1	116.0	20.4	8.0	0.8	0.16	0.01	0.28
6A	70.9	114.1	20.4	7.4	-	-	-	-
6	70.7	113.8	20.2	8.1	3.3	0.27	0.30	0.74
8	69.6	112.0	20.2	7.5	3.2	0.26	0.25	0.74
9	67.2	108.1	20.3	6.9	2.6	0.30	0.24	0.66
10	65.6	105.6	20.7	6.4	2.1	0.31	0.22	0.62
11A	63.7	102.5	21.1	5.8	-	-	-	-
11	63.4	102.0	20.9	5.8	1.9	0.34	0.27	0.62
13	61.7	99.3	20.8	5.5	1.9	0.34	0.26	0.63
15	59.6	95.9	20.6	5.8	1.6	0.40	0.21	0.56
17	58.6	94.3	20.7	5.8	1.7	0.41	0.22	0.60
18	57.1	91.9	20.7	6.0	1.6	0.43	0.20	0.58
19	52.6	84.7	20.8	6.1	1.5	0.45	0.16	0.57
19A	51.1	82.2	-	6.4	-	-	-	-

(Continued)

TABLE 2-12. (Concluded)

1978

Station Number	River Mile	River Kilometer	Temp. (°C)	D.O. (mg/l)	BOD_5 (mg/l)	NO_3-NO_2-N (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
3	72.1	116.0	18.9	8.6	0.5	0.20	0.02	0.27
6A	70.9	114.1	19.3	8.3	-	-	-	-
6	70.7	113.8	19.0	8.8	3.1	0.27	0.27	0.71
8	69.6	112.0	19.0	8.5	2.3	0.27	0.21	0.68
9	67.2	108.1	19.2	8.0	2.1	0.26	0.20	0.71
10	65.6	105.6	19.2	7.4	1.6	0.28	0.20	0.66
11A	63.7	102.5	19.9	7.4	-	-	-	-
11	63.4	102.0	19.3	7.6	1.3	0.28	0.16	0.58
13	61.7	99.3	18.5	6.9	1.5	0.30	0.19	0.65
15	59.6	95.9	18.6	7.0	1.4	0.30	0.17	0.54
17	58.6	94.3	18.5	7.0	1.3	0.30	0.17	0.53
18	57.1	91.9	18.5	7.0	1.4	0.32	0.17	0.54
19	52.6	84.7	18.7	7.0	1.2	0.35	0.16	0.52
19A	51.1	82.2	18.8	7.0	-	-	-	-

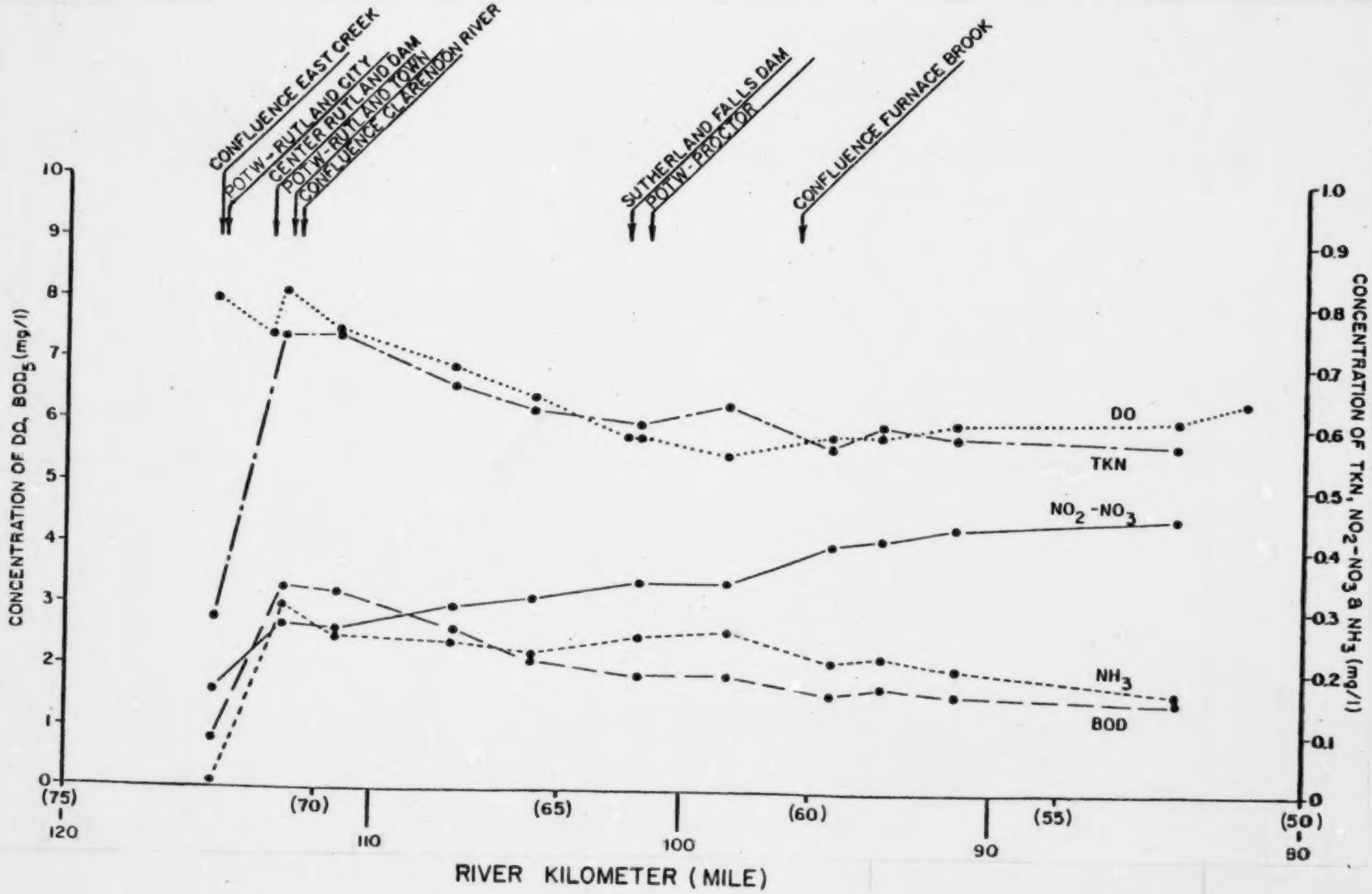

Figure 2-4. Profile of mean water quality data values (1977) (after Van Benschoten and Clarkson, 1979a).

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(PREVIOUSLY CIN. EPA FORM 287)
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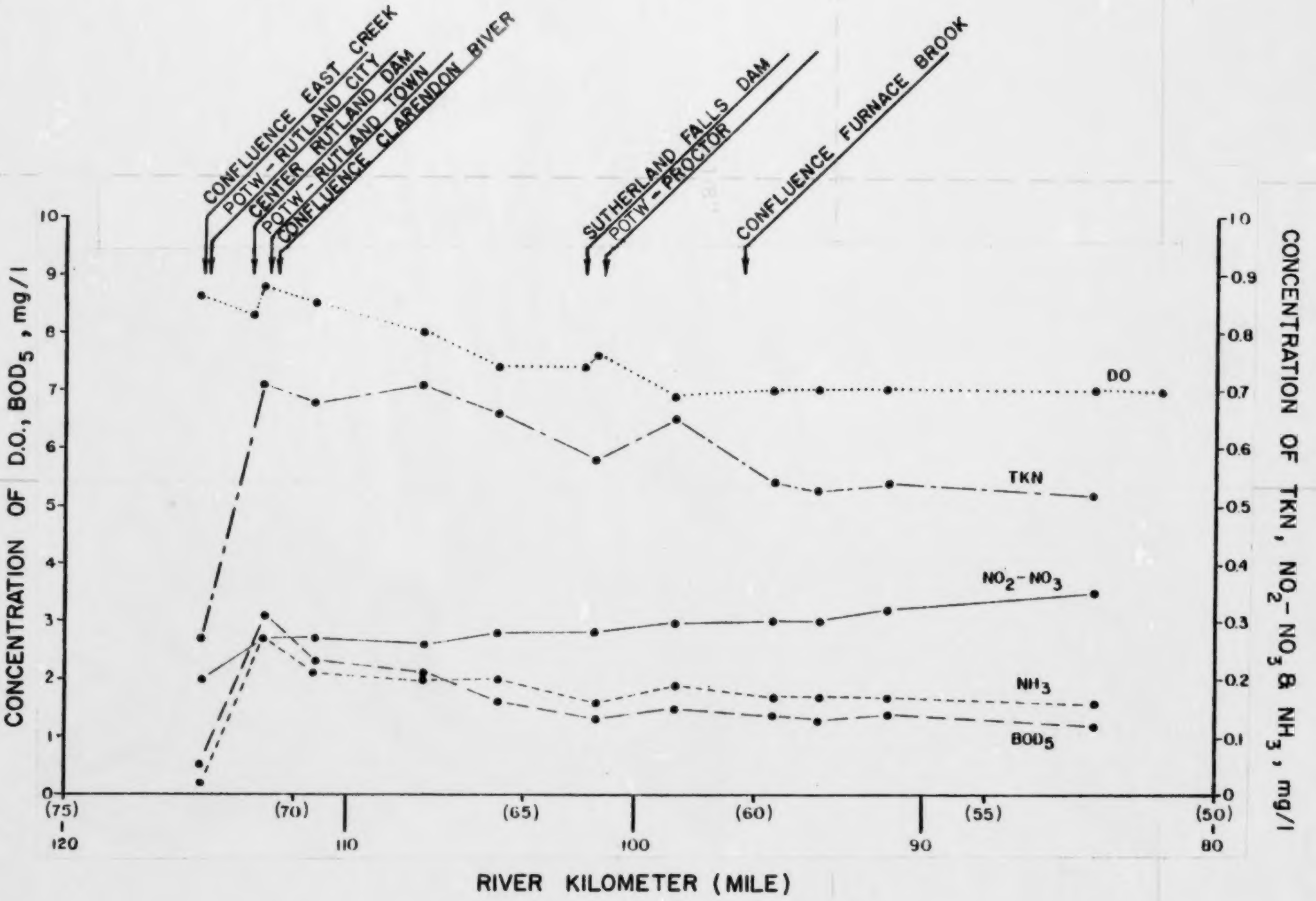

Figure 2-5. Profile of mean water quality data values (1978) (after Van Benschoten and Clarkson, 1979a).

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(PREVIOUSLY CIN. EPA FORM 287)

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TABLE 2-13. CARBONACEOUS DEOXYGENATION RATE COEFFICIENTS, K_1* (after Van Benschoten and Clarkson, 1979b)

Station Number	Facility	Rate Coefficients, K_1(1977)		Rate Coefficients, K_1(1978)	
		(day^{-1}/ base e)	(day^{-1}/ base 10)	(day^{-1}/ base e)	(day^{-1}/ base 10)
1	Rutland City	0.21	0.09	0.37	0.16
4	West Rutland	0.25	0.11	0.25 [b]	0.11 [b]
7	Rutland Town	0.30 [a]	0.13 [a]	0.30	0.13
12	Proctor	0.23	0.10	0.25	0.11
16	Pittsford	0.09	0.04	0.09 [b]	0.04 [b]

*All reaction rate coefficients are specified at 293°K (20°C/68°F).

[a] Reaction rate coefficient based on 1978 long-term BOD data.

[b] Reaction rate coefficient based on 1977 long-term BOD data.

TABLE 2-14. IN-STREAM REACTION RATE COEFFICIENTS[#] (after Van Benschoten and Clarkson, 1979a)

Data Description	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 7	Reach 8
Carbonaceous deoxygenation rate coefficient, K_1[*]								
K_1 (day^{-1}/base e)	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
K_1 (day^{-1}/base 10)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
CBOD removal rate coefficient, K_c[*]								
K_c (day^{-1}/base e)	0.23	0.23	0.30	0.69	0.23	0.69	0.092	0.09
K_c (day^{-1}/base 10)	0.10	0.10	0.13	0.30	0.10	0.30	0.04	0.04
NBOD removal rate coefficient, K_n								
K_n (day^{-1}/base e)	0.23	0.23	0.09	0.21	0.02	0.23	0.02	0.05
K_n (day^{-1}/base 10)	0.10	0.10	0.04	0.09	0.01	0.10	0.01	0.02
CBOD removal rate coefficient due to settling, K_s								
K_s (day^{-1}/base e)	1.52	-	-	-	-	-	-	-
K_s (day^{-1}/base 10)	0.66	-	-	-	-	-	-	-
Atmospheric reaeration rate coefficient, K_2								
K_2 (day^{-1}/base e)	0.46	1.31	0.07	0.18	0.02	0.46	0.35	0.35
K_2 (day^{-1}/base 10)	0.20	0.57	0.03	0.08	0.01	0.20	0.15	0.15
Dam reaeration coefficient, K_{1ad}								
K_{1ad} (day^{-1}/base e)	-	0.014	-	-	-	-	-	-
K_{1ad} (day^{-1}/base 10)	-	0.006	-	-	-	-	-	-

[#] All reaction rate coefficients are specified at 20°C (68°F).

[*] K_1 and K_c represent deoxygenation due to biochemical oxidation of organic carbonaceous compounds. K_1 is measured in a laboratory test, while K_c represents reactions in the river. In theory the two are the same, but in practice this is rarely the case since the laboratory test does not mimic river conditions well.

are given in Table 2-4 and the rate coefficients for each reach are given in Table 2-14. The nitrification lag time was set to zero.

Since chemical reaction rates are highly temperature dependent, the rate coefficients are specified at a temperature of 20°C (68°F). To find the reaction rate coefficient at a temperature other than 20°C the following formula may be used:

$$K_T = K_{20} \cdot \theta^{(T-20)} \qquad (2\text{-}3)$$

where K_T = rate coefficient at temperature T,

K_{20} = rate coefficient at 20°C (68°F),

θ = temperature correction factor, and

T = water temperature (°C).

The values of the temperature correction factor, θ, are given in Table 2-15.

TABLE 2-15. TEMPERATURE CORRECTION FACTORS FOR REACTION RATE COEFFICIENTS.

Reaction Rate Coefficient	Symbol	Temperature Correction Factor
CBOD deoxygenation	K_1	1.04
In-stream CBOD removal	K_c	1.02
In-stream NBOD removal	K_n	1.02
BOD settling	K_s	1.02
Atmospheric reaeration	K_2	1.02
Dam reaeration	K_{1ad}	1.02

2-4-3. Measurement Listing

The sampling stations are listed in Table 2-1 and shown in Figure 2-1. The parameters measured at each station are given in Table 2-16. These parameters were measured every four to five hours during the two intensive surveys, and the complete collection of measurements is given in the computer data set. The parameters for each station were measured at nineteen time intervals during the 1977 survey, and at eighteen intervals during the 1978 survey. However, it should be noted that the last three runs for each station during the 1978 survey took place after an

TABLE 2-16. PARAMETERS MEASURED AT EACH SAMPLING STATION

Station Number	Parameters Measured*					
	Temp. (00010)	D.O. (00300)	BOD_5 (00310)	NO_3-NO_2-N (00630)	NH_3-N (00610)	TKN (00625)
1			x	x	x	x
2	x	x	x	x	x	x
3	x	x	x	x	x	x
4			x	x	x	x
5	x	x	x	x	x	x
6A	x	x				
6	x	x	x	x	x	x
7		x	x	x	x	
8	x	x	x	x	x	x
9	x	x	x	x	x	x
10	x	x	x	x	x	x
11A	x	x				
11	x	x	x	x	x	x
12			x	x	x	x
13	x	x	x	x	x	x
14	x	x	x	x	x	x
15	x	x	x	x	x	x
16			x	x	x	x
17	x	x	x	x	x	x
18	x	x	x	x	x	x
19	x	x	x	x	x	x
19A	x	x				

*The numbers in parentheses below parameter names are the STORET codes for the parameters.

intense thunderstorm that had a considerable effect on flow rates and river chemistry, so the last three groups of measurements for each station do not represent steady state low flow conditions.

2-4-4. Sampling Techniques

This report sub-section was abstracted directly from the Vermont State Agency of Environmental Conservation report "Otter Creek Wasteload Allocation Study Part A: Report of Data" (Van Benschoten and Clarkson, 1979a).

Collection Methods--

For each of the wasteload allocation studies, river and wastewater sampling runs commenced at 8:00 a.m. the first day, and continued at four hour intervals throughout the study period. A description and map of sampling locations are presented in Table 2-1 and Figure 2-1, respectively.

Sample bottles were acid washed in the laboratory and rinsed with distilled water. Prior to collection, bottles were again rinsed with river water or POTW effluent.

All stream samples were taken from the main current in order to obtain a representative, well mixed sample. Except for those samples collected from bridges, the collection of chemistry samples was accomplished either by means of a long handled dip sampler or by filling sample bottles by hand from the shoreline, depending on stream flow characteristics. Samples from bridges were collected using a standard Kemmerer water sampler.

Water samples for dissolved oxygen were collected using either the dip sampler or Kemmerer in the manner described by Welch (1948).

Effluent samples from POTW's were unchlorinated and collected either by a dip sampler (not the same one used for river water samples) or by hand. At the West Rutland POTW a composite sample of the effluent was collected from each of the two clarifiers.

Samples were iced and delivered to the laboratory within several hours of collection.

For quality control purposes twenty percent true duplicates were collected in 1978.

Temperature--

Temperature in the streams was measured in situ using mercury thermometers calibrated from -20°C to 110°C with 1°C subdivisions. The thermometers were standardized against a National Bureau of Standards thermometer for temperatures obtained during stream measurements.

Dissolved Oxygen (D.O.)--

Dissolved oxygen was determined as specified in Standard Methods for the Examination of Water and Wastewater (APHA, 1975) using the azide modification of the Winkler method.

Biochemical Oxygen Demand (BOD)--

Biochemical Oxygen Demand was determined as specified in Section 507 of Standard Methods for the Examination of Water and Wastewater (APHA, 1975), except for the following changes and modifications.

1. Effluent samples were analyzed using two dilutions per sample which were chosen on the basis of past data. River samples were analyzed without dilution and nutrients were added directly to the samples in the concentration of 1 mg/l.

2. All samples were incubated within 8 hours of collection at 20°C ± 1°C. When the incubated bottles were transferred from the analysis site to the larger incubation facilities in Montpelier, transport time ranged from one to two hours.

3. All dissolved oxygen analysis for BOD determinations were done using the azide modification of the Winkler method.

Quality control consisted of glucose-glutamic acid standards seeded with POTW effluent. Approximately two such standards were prepared for each day of the study. A control blank was run on all dilution water used in the studies and the control values were in the range of 0.0 mg/l to 0.6 mg/l with a mean value of 0.2 mg/l.

Nitrogen (N)--

The chemical analyses for nitrogen were determined in accordance with the procedures outlined in Methods for Chemical Analysis of Water and Wastes (EPA, 1974), except for the variations explained in the following descriptions of methods and quality control. All results of nitrogen determinations are expressed in mg/l as nitrogen.

Nitrate-Nitrite Nitrogen (NO_3-NO_2-N)--

Nitrate-nitrite was measured using a Technicon Autoanalyzer II according to the automated cadmium reduction method, except for the following differences in reagent preparation:

1. Ammonium chloride solution: 10 g of ammonium chloride were dissolved in alkaline distilled water (pH 8.5, adjusted by use of ammonium hydroxide). The solution was diluted to one liter and 0.5 ml of Brij-35 added.

2. Color reagent solution: To 1500 ml of distilled water, 200 ml of concentrated phosphoric acid and 20 g of sulfanilimide were added. After complete dissolution, 1.0 g of N-1-naphthylethylenediamine dihydrochloride was added. The solution was diluted to 2 liters and stored in a cool, dark place.

Quality control consisted of analyzing 20% of all samples in duplicate and including reagent blanks and standards in each autoanalyzer run.

Ammonia Nitrogen (NH_3-N)--

Ammonia was measured using a Technicon Autoanalyzer II according to the automated colorimetric phenate method except that the alkaline phenol reagent was modified by the addition of 36 g of sodium hydroxide instead of 32 g.

Quality control consisted of analyzing 20% of all samples in duplicate and including reagent blanks and standards in each autoanalyzer run.

Total Kjeldahl Nitrogen (TKN)--

Total Kjeldahl nitrogen was analyzed by the manual method using a micro-glassware system and Nesslerization, except for the following variations in the prescribed procedure:

1. Samples collected at river stations with low concentrations of TKN were digested in two successive 50 ml batches for a total aliquot of 100 ml.

2. The samples were distilled into 5 ml of 4% boric acid because the increased strength of the acid would result in better capture.

Quality control consisted of analyzing all samples in duplicate and reanalyzing, in duplicate, any sample which had poor replicates. Standards were run at least once every eight hour shift and reagent blanks were run every eight hour shift and after every reagent change. Both standards and blanks were taken through the entire digestion and distillation procedure.

Variability Analysis of Duplicate Samples--

The duplicate samples collected during the Otter Creek and other wasteload allocation studies in 1978 were analyzed to determine the variability in the water quality analysis results. The sources of variability may include (1) a sample collected from a river or POTW which was not representative, (2) poor sampling technique, or (3) variability due to method of analysis.

Water quality analysis results generally demonstrate that as the mean value of duplicate samples increases, so too does the standard deviation. Therefore, in order to analyze similar populations, both the river data and water pollution control facility data were divided into various groups as shown in Table 2-17.

Each standard deviation reported in Table 2-17 is the square root of the mean variance of the duplicates in each particular group. This approach is considered to result in the best estimate of the variability. Any standard deviation which is based on less than ten duplicate samples should not be considered reliable.

TABLE 2-17. VARIABILITY ANALYSIS OF DATA, 1978 (after Van Benschoten and Clarkson, 1979b)

		Otter Creek Data		All 1978 Data	
Test	Sample	Number Duplicates	Std. Dev. (mg/1)	Number Duplicates	Std. Dev. (mg/1)
D.O.	Rivers - all	65	0.12	259	0.15
BOD$_5$	Rivers - all	38	0.16	88	0.19
	0.1-1.0 mg/1	10	0.14	19	0.13
	1.1-2.0 mg/1	22	0.15	31	0.15
	2.1-4.0 mg/1	6	0.2	33	0.2
	4.1-6.5 mg/1	0	-	5	0.3
	POTW				
	1.0-10 mg/1	2	0.40	17	0.64
	11-30 mg/1	5	1	10	2
	31-130 mg/1	3	6	12	5
	131-300 mg/1	6	6	9	11
NO_2-NO_3	Rivers - all	41	0.009	89	0.016
	POTW				
	0.02-1.0 mg/1	10	0.035	13	0.041
	1.1-12 mg/1	2	0.01	13	0.4
	13-40 mg/1	0	-	8	2.4
NH_3	Rivers - all	44	0.005	86	0.012
	0.004-0.100 mg/1	11	0.002	45	0.006
	0.101-750 mg/1	33	0.005	41	0.016
	POTW				
	0.01-1.0 mg/1	0	-	10	0.052
	1.1-10 mg/1	3	0.2	11	0.4
	11-50 mg/1	13	1	19	1
TKN	Rivers - all	42	0.05	100	0.04
	POTW				
	0.08-1.0 mg/1	0	-	11	0.06
	1.1-10 mg/1	1	0.6	8	0.2
	11-50 mg/1	14	1.3	25	1.3

2-5. COMPUTER DATA SET

The biochemical data which were measured in the two intensive Otter Creek Surveys of August 1-4, 1977 and August 1-4, 1978 are included in the computer data set. The parameters which were measured at each station are listed in Table 2-16, and their mean values are given in Tables 2-10, 2-11 and 2-12, and in Figures 2-4 and 2-5.

2-6. REFERENCES

1. Carter, R.W., and Davidian, J., "General Procedure for Gaging Streams," Techniques of Water Resources Investigation of the USGS, Book 3, Chapter A6, U.S. Government Printing Office, Washington, D.C., 1968.

2. American Public Health Association et al., Standard Methods for the Examination of Water and Wastewater, 14th ed., APHA, Washington, DC, 1975.

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4. Porteous, D.P., "Otter Creek Study, 1976, Report of Data," Environmental Protection Agency, Lexington, MA, January 1977.

5. Quirk, Lawler and Matusky Engineers, "Systems Analysis for Water Pollution Control," Massachusetts Water Resources Commission, Division of Water Pollution Control, Westborough, MA, 1971.

6. Resource Analysis Inc., "STREAM 7A Users Manual," Massachusetts Water Resources Commission, Division of Water Pollution Control, Westborough, MA, 1978.

7. Van Benschoten, J., and Clarkson, B., "Otter Creek Wasteload Allocation Study Part A: Report of Data," State of Vermont Agency of Environmental Conservation, Montpelier, VT, January 1979a.

8. Van Benschoten, J., and Clarkson, B., "Otter Creek Wasteload Allocation Study Part B: Mathematical Modeling Report," State of Vermont Agency of Environmental Conservation, Montpelier, VT, May 1979b.

9. Welch, P.S., Limnological Methods, Blakiston Co., Philadelphia, PA, 1948.

SECTION 3

UPPER WINOOSKI RIVER

3-1. INTRODUCTION

The Winooski River has its source in the northeast corner of Washington County, Vermont, and flows west through Montpelier to Lake Champlain. The river is 145 km (90 mi) long, and has a drainage area of 2,800 km^2 (1,080 mi^2).

The information presented in this report section is derived from a waste allocation study by the State of Vermont Agency of Environmental Conservation. The waste allocation study consisted of two intensive surveys of the Stevens Branch close to its junction with the Winooski River, and the Winooski River from just above its junction with the Stevens Branch to the Interstate 89 bridge in Montpelier. The studied section of the Stevens Branch is 5.5 km (3.4 mi) long, and receives the effluent from two publicly owned treatment works (POTW's). The studied section of the Winooski River is 6.7 km (4.2 mi) long.

The two intensive surveys from which this report section is drawn were conducted on August 22-24, 1978 and July 9-11, 1979.

3-2. SOURCE LITERATURE

This study was chosen for inclusion in the modelling database shortly after the data report (Van Benschoten and Clarkson, 1979) was issued. At that time the Vermont Agency of Environmental Conservation intended to do a wasteload allocation study and issue a modelling report on the river. The modelling report was expected to clarify the collected data and provide information of biochemical reaction coefficients. However, the Vermont Agency of Environmental Conservation later reversed its decision, and the modelling report will not be released. Consequently, the report by Van Benschoten and Clarkson (1979) remains the only data source, and no modelling formation is included in this section of the report. The information on Stevens Branch cross sections and on flow rates from the Stevens Branch was based on a personal communication from P. LaFlamme of the Vermont State Agency of Conservation, August 1983.

3-3. RIVER BASIN DESCRIPTION

3-3-1. Study Area

The river studied in this report is the 5.5 km (3.4 mi) section of the Stevens Branch from Barre City to its junction with the Winooski River, and the 6.7 km (4.2 mi) section of the Winooski River from just upstream of its junction with the Stevens Branch to the Interstate 89 bridge in Montpelier. This study area is shown in Figure 3-1, and station locations are given in Table 3-1.

3-3-2. Hydrologic Data

Point Inflows--

The studied section of the Winooski River has three tributaries: the Stevens Branch, Blanchard Brook, and the North Branch. There is a USGS gaging station on the Winooski River at river kilometer 88.5 (mile 55.0), 0.5 km upstream of the Interstate 89 bridge in Montpelier. There is also a USGS gage on the North Branch 5.6 km (3.5 mi) upstream from its confluence with the Winooski River. Blanchard Brook is assumed to contribute a negligible flow to the Winooski River, so that dilution effects can be estimated once the inflows from the Stevens Branch are known.

The Vermont State Agency of Environmental Conservation made measurements of velocity in the Stevens Branch and the Winooski River just upstream of their confluence in 1979. From these measureemnts of the velocity profiles flow rates were calculated. Unfortunately these measurements produced calculated flows which were much too low to account for the measured flows at the I-89 bridge gaging station. The State of Vermont Agency of Vermont assumed that the water velocity meter was calibrated to give readings which were too low, and the flow rates were scaled up until the sum of flows from the Stevens Branch, the Winooski River above the Stevens Branch confluence, and the North Branch, equalled the measured flow of the Winooski River at the USGS gage in Montpelier. The Winooski River and tributary flows are given in Table 3-2. The mean seven consecutive day low flow with a recurrence interval of 10 years (7Q10) is 1.7 m^3/s (60 ft^3/sec) at the Montpelier USGS gage.

The section of the Stevens Branch in the study area receives flows from the Barre and Berlin POTW's and from Pond Brook. The mean daily effluent flow rates from the POTW's are given in Table 3-3, and inflows from Pond Brook are assumed to be negligible.

Non-Point Inflows--

Non-point inflows cannot be back-calculated from a mass-balance of point inflows and outflows from the study area because the point inflows were estimated using such a mass balance. The Vermont State Agency of Environmental Conservation made their estimation of point flows using the assumption that non-point inflows and loads are negligible.

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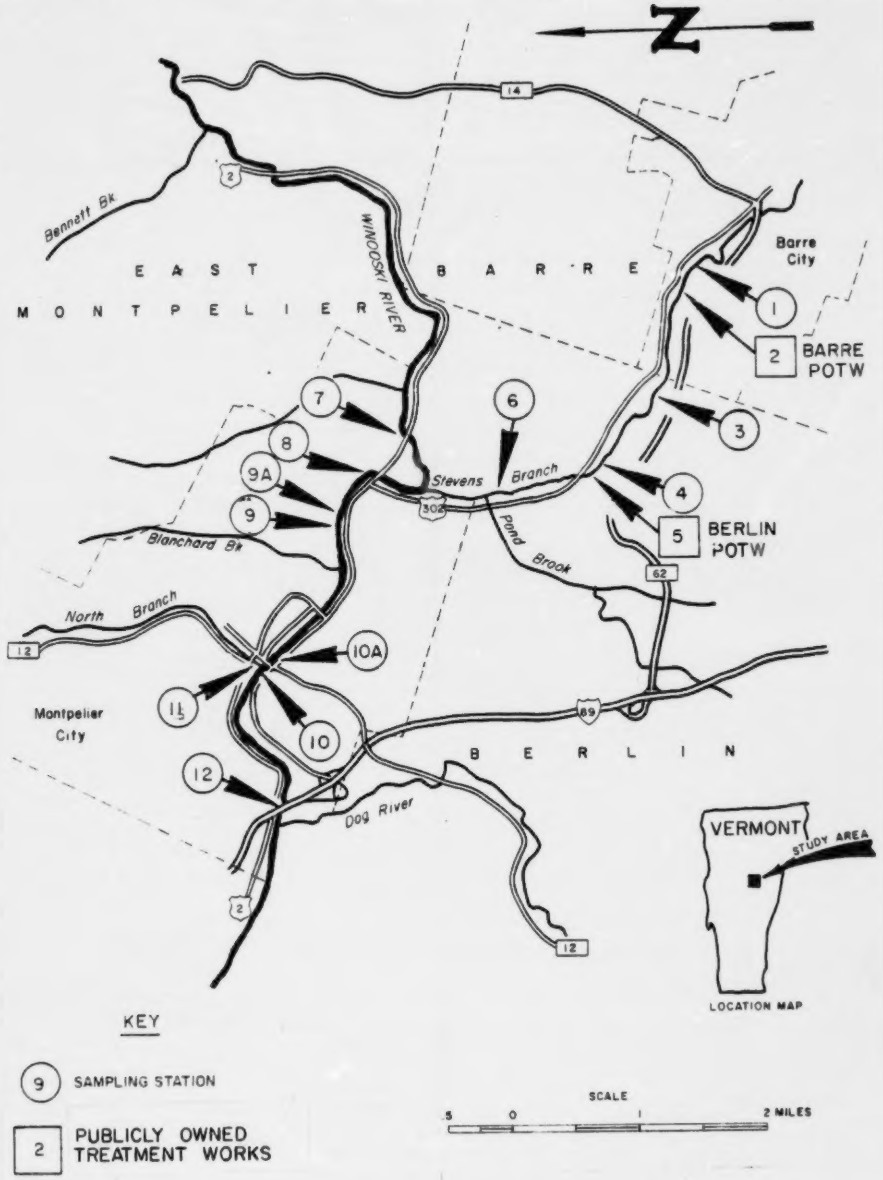
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14
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WINOOSKI RIVER
EAST MONTPELIER
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Barre City
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9A
9
Stevens Branch
302
4
5 BERLIN POTW
Pond Brook
62
Blanchard Bk
North Branch
12
10A
11½
10
Montpelier City
89
BERLIN
12
Dog River
2
12
VERMONT
STUDY AREA
LOCATION MAP
KEY
9 SAMPLING STATION
2 PUBLICLY OWNED TREATMENT WORKS
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Figure 3-1. Upper Winooski study area (after Van Benschoten and Clarkson, 1979).

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TABLE 3-1. LOCATION OF SAMPLING STATIONS (after Van Benschoten and Clarkson, 1979)

Station Number	River Mile	River Km	Location
1	61.9	99.6	Stevens Branch: Willey Street Bridge in Barre
2	61.8	99.4	POTW - Barre: Discharges to Stevens Branch
3	60.8	97.8	Stevens Branch: Behind Collins Furniture Store, Route 302
4	60.2	96.8	Stevens Branch: Just above Berlin POTW
5	60.2	96.9	POTW - Berlin: Discharges to Stevens Branch
6	59.1	95.1	Stevens Branch: First bridge above confluence with Winooski River, behind highway garage
7	58.5	94.1	Winooski River at 0.4 mi (0.6 km) above confluence with Stevens Branch: Route 2 Bridge
8	57.9	93.2	Winooski River: Route 2 Bridge below confluence with Stevens Branch
9A	57.5	92.5	Winooski River: Just above Pioneer Street Dam
9	57.4	92.4	Winooski River: At ledge below Pioneer Street Dam
10A	56.2	90.4	Winooski River: Main Street Bridge
10	56.1	90.3	Winooski River: Below Bailey Dam in Montpelier
11	56.1	90.3	North Branch at 0.1 mi (0.2 km): Just below weir, behind Grand Union
12	54.7	88.0	Winooski River: Under I-89 Bridge, Route 2

TABLE 3-2. UPPER WINOOSKI RIVER AND TRIBUTARY DAILY FLOWS (after Van Benschoten and Clarkson, 1979)

1978

Location	Date		Mean	
	08/22 (ft^3/sec)	08/23 (ft^3/sec)	(ft^3/sec)	(m^3/s)
North Branch	6.2	5.8	6.0	0.17
Winooski R., at USGS gage in Montpelier	124	126	125	3.54

1979

Location	Date			Mean	
	07/10 (ft^3/sec)	07/11 (ft^3/sec)	07/12 (ft^3/sec)	(ft^3/sec)	(m^3/s)
Stevens Branch above Winooski R. junction*				28	0.79
Winooski R. above Stevens Branch junction*				100	2.83
North Branch	14	13	13	13	0.38
Winooski R. at USGS gage in Montpelier	150	417	128	142	4.01

*Estimated flows from personal communication with P. LaFlamme, Vermont State Agency of Environmental Conservation. See Section 3-3-2.

TABLE 3-3. MEAN DAILY FLOWS FROM PUBLICLY OWNED TREATMENT WORKS (after Van Benschoten and Clarkson, 1979)

1978

Station Number	Facility	Date 08/22 (mgd)	08/23 (mgd)	Mean (mgd)	(ft^3/sec)	(m^3/s)
2	Barre	2.59	2.74	2.66	4.13	0.117
5	Berlin	0.163	0.167	0.165	0.256	0.00725

1979

Station Number	Facility	Date 07/10 (mgd)	07/11 (mgd)	07/12 (mgd)	Mean (mgd)	(ft^3/sec)	(m^3/s)
2	Barre	2.57	2.05	2.39	2.34	3.62	0.103
5	Berlin	0.187	0.199	0.182	0.189	0.294	0.00833

3-3-3. Hydraulic Data

River Cross-Sections--
Unfortunately, only two cross-sections are available, and both are from the Stevens Branch. The cross sectional coordinates are given in Table 3-4.

Stream Slope--
The streambed is shown in Figure 3-2. The river section from Willey Street Bridge (river kilometer 99.6/mile 61.9) to Pioneer Street Dam (river kilometer 92.5/mile 57.5) has a generally uniform slope averaging approximately 2.0×10^{-3} (10.6 ft/mi).

Mannings Roughness Coefficient--
This parameter must be estimated.

Flow Velocities--
The average flow velocities for this river section were derived from time of travel studies. The river section was divided into two reaches, and for each reach the time of travel was determined as a function of the flow rate at the USGS gaging station at river kilometer 88.5 (mile 55.0) (see Section 3-3-5). The average expected flow velocities derived from the time of travel studies are given in Table 3-5.

Instantaneous flow velocities were measured across two cross sections in the Stevens Branch. However, these data are not presented because the Vermont State Agency of Conservation decided that the velocity meter was incorrectly calibrated.

3-3-4. Climatological Data

Precipitation--
Prior to and during the 1978 and 1979 intensive surveys, generally dry conditions prevailed. The daily precipitation measurements during the intensive surveys are given in Table 3-6. As shown in the table, 1.7 cm (0.67 in) of precipitation was measured on August 24, 1978. This event began at about 1:00 a.m. and continued through the afternoon of August 24. Since the survey ended at 6:00 a.m., and the Montpelier Weather Station measured daily precipitation at 12:00 noon, this value includes precipitation which fell between the end of the study and the measuring time. Thus the amount of precipitation that fell during the study period is unknown, but it does not appear to have made a noticeable impact on the water quality measurements.

Pan Evaporation--
Although not measured as part of the waste allocation study, daily pan evaporation is available for nearby locations from the monthly "Climatological Data" published by the National Weather Service.

TABLE 3-4. CROSS-SECTION COORDINATES FROM STEVENS BRANCH (personal communication, P. LaFlamme, Vermont State Agency of Environmental Conservation).

Stevens Branch Downstream of Pond Brook Confluence	
Horizontal Distance (ft)	Depth (ft)
0	0
2	0.4
4	0.7
6	0.9
8	0.9
10	0.9
12	0.8
14	0.7
16	0.7
18	0.8
20	0.8
22	0.7
24	1.0
26	1.1
28	1.2
30	1.4
32	1.0
34	0.9
36	0

Stevens Branch at Station 6*	
Horizontal Distance (ft)	Depth (ft)
0	0
1	1.0
2	1.1
3	1.2
4	1.2
5	1.3
6	1.3
7	1.2
8	1.2
9	1.2
10	1.2
11	1.3
12	1.3
13	1.2
14	1.2
15	1.2
16	1.1
17	1.1
18	1.1
19	1.2
21	1.1
23	1.2
25	1.2
27	1.2
29	1.1
31	0.7
33	0.7
35	0.6
36	0

*See Figure 3-1 and Table 3-1 for location of Station 6.

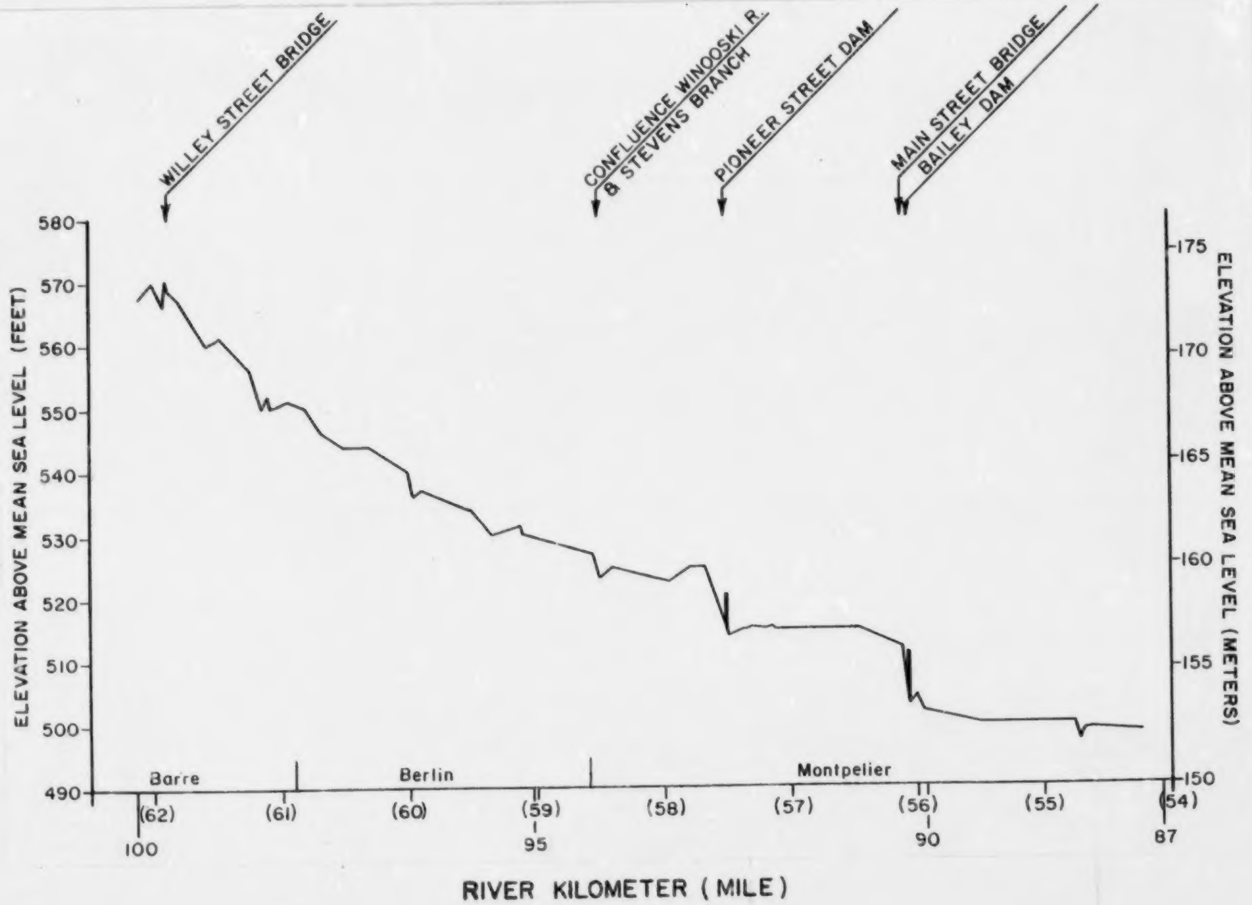

Figure 3-2. Streambed profile of the Upper Winooski River (after Van Benschoten and Clarkson, 1979).

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TABLE 3-5. EXPECTED TIMES OF TRAVEL AND AVERAGE FLOW VELOCITIES

1978, Flow Rate = 3.54 m^3/sec (125 ft^3/sec)

From		To		Time of Travel	Average Velocity	
River Km	River Mile	River Km	River mile	(hrs)	(m/sec)	(ft/s)
99.4	61.8	94.6	58.8	9.8	0.14	0.45
94.6	58.8	88.0	54.7	12.6	0.15	0.48

1979, Flow rate = 4.02 m^3/s (142 ft^3/sec)

From		To		Time of Travel	Average Velocity	
River Km	River Mile	River Km	River mile	(hrs)	(m/sec)	(ft/s)
99.4	61.8	94.6	58.8	8.9	0.15	0.49
94.6	58.8	88.0	54.7	10.8	0.17	0.56

TABLE 3-6. DAILY PRECIPITATION (MONTPELIER, VERMONT) (after Van Benschoten and Clarkson, 1979)

Date	Rainfall cm	Rainfall inches	Date	Rainfall cm	Rainfall inches
780822	0	0	790709	0	0
780823	0	0	790710	0	0
780824	1.74	0.67	790711	Trace	Trace
			790712	0	0

TABLE 3-7. MAXIMUM DAILY AIR TEMPERATURES (MONTPELIER, VERMONT) (after Van Benschoten and Clarkson, 1979)

	Max. Temp.		Min. Temp.			Max. Temp.		Min. Temp.	
Date	(°F)	(°C)	(°F)	(°C)	Date	(°F)	(°C)	(°F)	(°C)
780822	80	26.7	48	8.9	790709	79	26.1	52	11.1
780723	75	23.9	48	8.9	790710	80	26.7	55	12.8
780824	55	12.8	52	11.1	790711	79	26.1	62	16.7
					790712	80	26.7	60	15.6

Ambient Temperatures--

Generally, high temperatures prevailed before and during the 1978 and 1979 surveys. The maximum and minimum daily air temperatures are shown in Table 3-7.

3-3-5. Sampling Techniques

Flow Rates--

The mean daily flow rates for the Winooski River were measured at a USGS gaging station at river kilometer 88.5 (mile 55.0), just upstream of the Interstate 89 bridge in Montpelier. The mean daily flow rates for the North Branch of the Winooski River were measured at a USGS gaging station 5.6 km (3.5 mi) upstream of its junction with the Winooski River.

Values for the instantaneous flow rates in the Stevens Branch, the North Branch and the Winooski River were derived from measurements of instantaneous velocity.

Flow Velocities--

Instantaneous flow velocities in the Stevens Branch, the North Branch and the Winooski River were measured on several occasions using a Marsh-McBirney model 207 portable water current meter. Depending on stream depth, velocities were measured at either the six-tenths depth or the eight-tenths and two-tenths depths (Carter and Davidian, 1978).

Average flow velocities were calculated by using time of travel and flow rate data. The Vermont Department of Water Resources conducted the time of travel studies using a Turner model III flow-through fluorometer and Rhodamine B dye. The river section was divided into two reaches, and time of travel measurements were made at flow rates ranging from 3.54 m^3/s (125 ft^3/sec) to 20.3 m^3/s (716 ft^3/sec), with three measurements for each reach. The time of arrival of the dye at the downstream end of the reach was determined by plotting a graph of dye concentration vs. time at the end of the reach. The mean time of arrival was determined as the centroid of the area under the curve. The average flow velocity over the reach is obtained by dividing the reach length by the mean time taken for dye to travel from one end of the reach to the other.

The data for flow rate Q, and time of travel, t, were fitted using an equation of the form

$$\left[\frac{Q_1}{Q_2}\right]^y = \frac{t_2}{t_1} \tag{3-1}$$

where y is a characteristic constant for each reach. Expected times of travel for the flow rates measured during the intensive surveys were derived using this equation.

Precipitation and Daily Air Temperatures--
The daily precipitation and maximum and minimum daily air temperatures were measured at the Montpelier Weather Station. Unfortunately, hourly precipitation measurements were not made at this station.

The information on daily precipitation and air temperatures were taken from:

National Oceanic and Atmospheric Administration,
Climatological Data, New England.
Volume 90, No. 8, August 1978.
Volume 91, No. 7, July 1979.

3-4. RIVER QUALITY DESCRIPTION

3-4-1. Major Pollution Sources

The major source of pollution to this section of the Winooski River is the effluent from two publicly owned treatment works which discharge into the Stevens Branch. The positions of the POTW's are given in Table 3-1 and Figure 3-1.

The average daily flow rates from the POTW's are given in Table 3-3, and the average effluent quality measurements are given in Table 3-8.

The State of Vermont Department of Water Resources calculated ultimate BOD loads using an assumed carbonaceous BOD decay rate, K_1, of 0.23 day^{-1}/base e (0.1 day^{-1}/base 10).

The average water quality measurements of the major tributaries to the studied river section are given in Table 3-9; their flow rates were given in Table 3-2. The mean data values were derived from sample readings taken at five hourly intervals during the intensive surveys. The detailed values and times of measurements are contained, by station number, in the computer data set.

3-4-2. Biochemical Data

Mean Data Values--
The mean values of the biochemical parameters measured at each station on the main study section of the river are presented in Table 3-10, and the profiles of the mean parameter values are shown in Figures 3-3, 3-4, and 3-5. The mean values of biochemical parameters measured at stations off the main study section of the river are presented in Table 3-9.

3-4-3. Measurement Listing

The sampling stations are listed in Table 3-1 and shown in Figure 3-1, while the parameters measured at each station are listed in Table 3-11.

TABLE 3-8. MEAN EFFLUENT QUALITY DATA VALUES FROM PUBLICLY OWNED TREATMENT WORKS (after Van Benschoten and Clarkson, 1979)

1978

Station Number	Facility	BOD_5 (mg/l)	NO_3-NO_2-N (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
2	Barre	7.1	3.4	8.2	9.2
5	Berlin	17	2.9	0.04	2.3

1979

Station Number	Facility	BOD_5 (mg/l)	NO_3-NO_2-N (mg/l)	NH_3-N (mg/l)	TKN (mg/l)	O-P (mg/l)	T-P (mg/l)
2	Barre	9.8	7.5	1.34	2.16	0.73	1.02
5	Berlin	15	0.27	2.1	3.9	3.6	4.4

TABLE 3-9. MEAN WATER QUALITY DATA VALUES FROM MAJOR TRIBUTARIES (after Van Benschoten and Clarkson, 1979)

1978

Station Number	Location	River Mile	River Kilometer	Temp. (°C)	DO (mg/l)	BOD_5 (mg/l)	NO_3-NO_2-N (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
7	Winooski R.	0.4	0.6	19.9	9.2	1.0	0.05	0.005	0.26
11	North Br.	0.1	0.2	20.6	7.4	1.4	0.09	0.04	0.33

1979

Station Number	Location	River Mile	River KM	Temp. (°C)	DO (mg/l)	BOD_5 (mg/l)	NO_3-NO_2-N (mg/l)	NH_3-N (mg/l)	TKN (mg/l)	O-P (mg/l)	T-P (mg/l)	CHL-a (mg/m^3)
7	Winooski R.	0.4	0.6	22.6	8.7	0.9	0.08	0.010	0.28	0.003	0.014	3.4
11	North Br.	0.1	0.2	22.4	7.3	1.7	0.16	0.13	0.51	0.018	0.047	2.2

TABLE 3-10. MEAN WATER QUALITY DATA VALUES FROM MAIN STUDY SECTION (after Van Benschoten and Clarkson, 1979)

				1978					
Station Number	Location	River Mile	River Kilometer	Temp. (°C)	DO (mg/1)	BOD_5 (mg/1)	NO_3-NO_2-N (mg/1)	NH_3-N (mg/1)	TKN (mg/1)
1	Stevens Br.	61.9	99.6	17.5	9.1	1.3	0.43	0.04	0.32
3	Stevens Br.	60.8	97.8	18.2	8.3	3.8	1.21	0.89	1.22
4	Stevens Br.	60.2	96.9	18.0	8.1	4.6	1.37	0.62	1.01
6	Stevens Br.	59.1	95.1	18.5	8.1	4.9	1.43	0.26	0.93
8	Winooski R.	57.9	93.2	20.0	9.2	2.0	0.36	0.06	0.39
9A	Winooski R.	57.5	92.5	20.2	9.1	-	-	-	-
9	Winooski R.	57.4	92.4	20.1	9.0	2.4	0.30	0.04	0.40
10A	Winooski R.	56.2	90.4	20.5	9.4	-	-	-	-
10	Winooski R.	56.1	90.3	20.4	9.0	2.9	0.28	0.04	0.47
12	Winooski R.	54.7	88.0	20.8	9.2	2.1	0.25	0.04	0.41

(Continued)

TABLE 3-10. (Concluded)

1979

Station Number	Location	River Mile	River Km	Temp. (°C)	DO (mg/1)	BOD_5 (mg/1)	NO_3-NO_2-N (mg/1)	NH_3-N (mg/1)	TKN (mg/1)	O-P (mg/1)	T-P (mg/1)	CHL-a (mg/m^3)
1	Stevens Br.	61.9	99.6	19.7	9.4	1.0	0.42	0.026	0.28	0.004	0.013	3.4
3	Stevens Br.	60.8	97.8	19.9	9.3	1.2	1.11	0.15	0.50	0.07	0.10	4.2
4	Stevens Br.	60.2	96.9	20.0	9.3	1.2	1.10	0.16	0.46	0.07	0.09	4.3
6	Stevens Br.	59.1	95.1	20.1	9.1	1.3	0.97	0.12	0.47	0.09	0.13	4.6
8	Winooski R.	57.9	93.2	22.4	8.9	0.9	0.34	0.05	0.36	0.024	0.042	3.0
9A	Winooski R.	57.5	92.5	22.3	8.8	-	-	-	-	-	-	-
9	Winooski R.	57.4	92.4	22.4	8.8	1.1	0.32	0.03	0.34	0.019	0.036	3.0
10A	Winooski R.	56.2	90.4	22.9	9.0	-	-	-	-	-	-	-
10	Winooski R.	56.1	90.3	22.8	8.7	1.1	0.30	0.04	0.37	0.016	0.033	3.9
12	Winooski R.	54.7	88.0	23.1	9.0	1.2	0.25	0.03	0.32	0.012	0.029	4.3

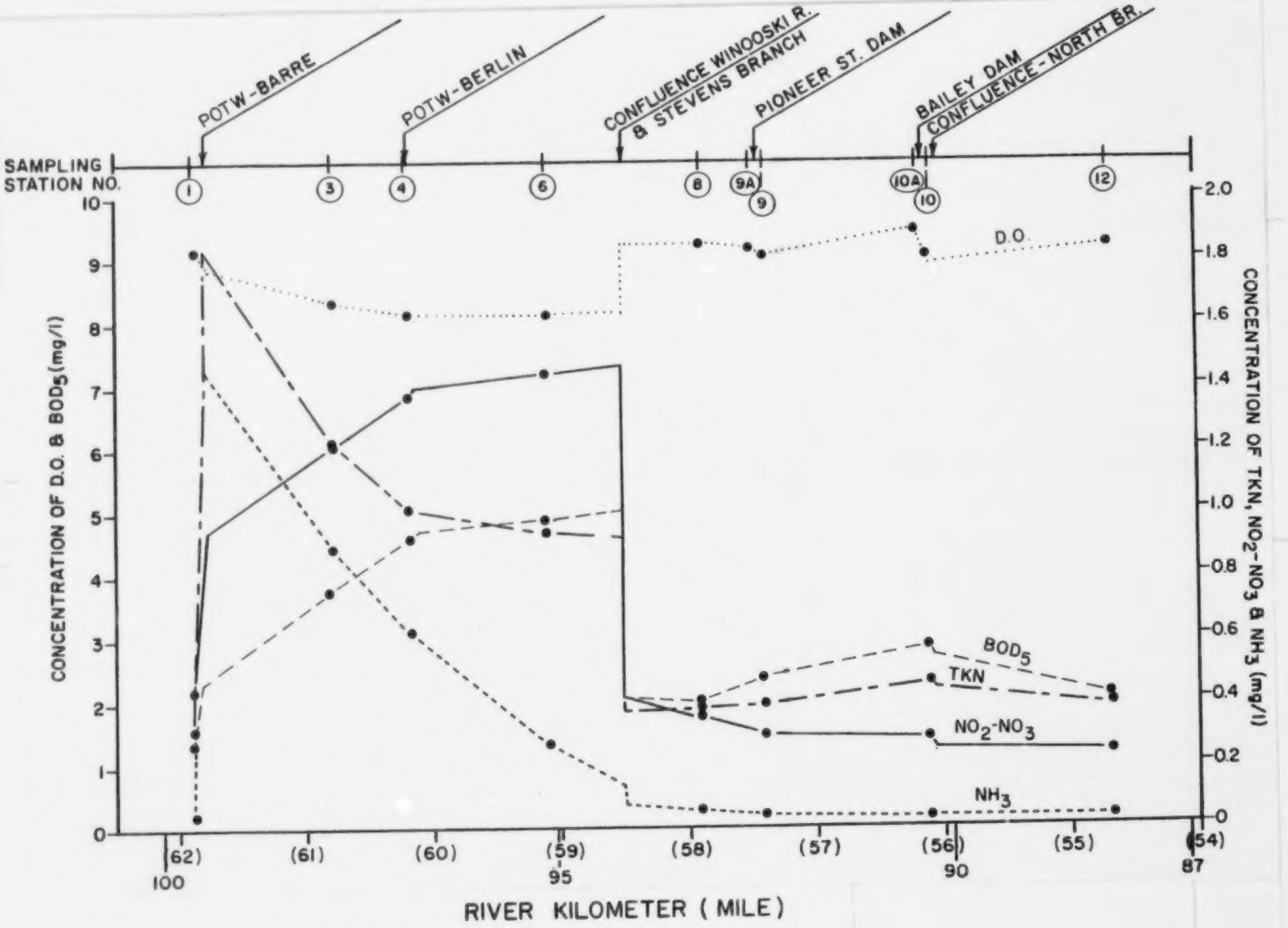

Figure 3-3. Profile of mean water quality parameter values (1978) (after Van Benschoten and Clarkson, 1979).

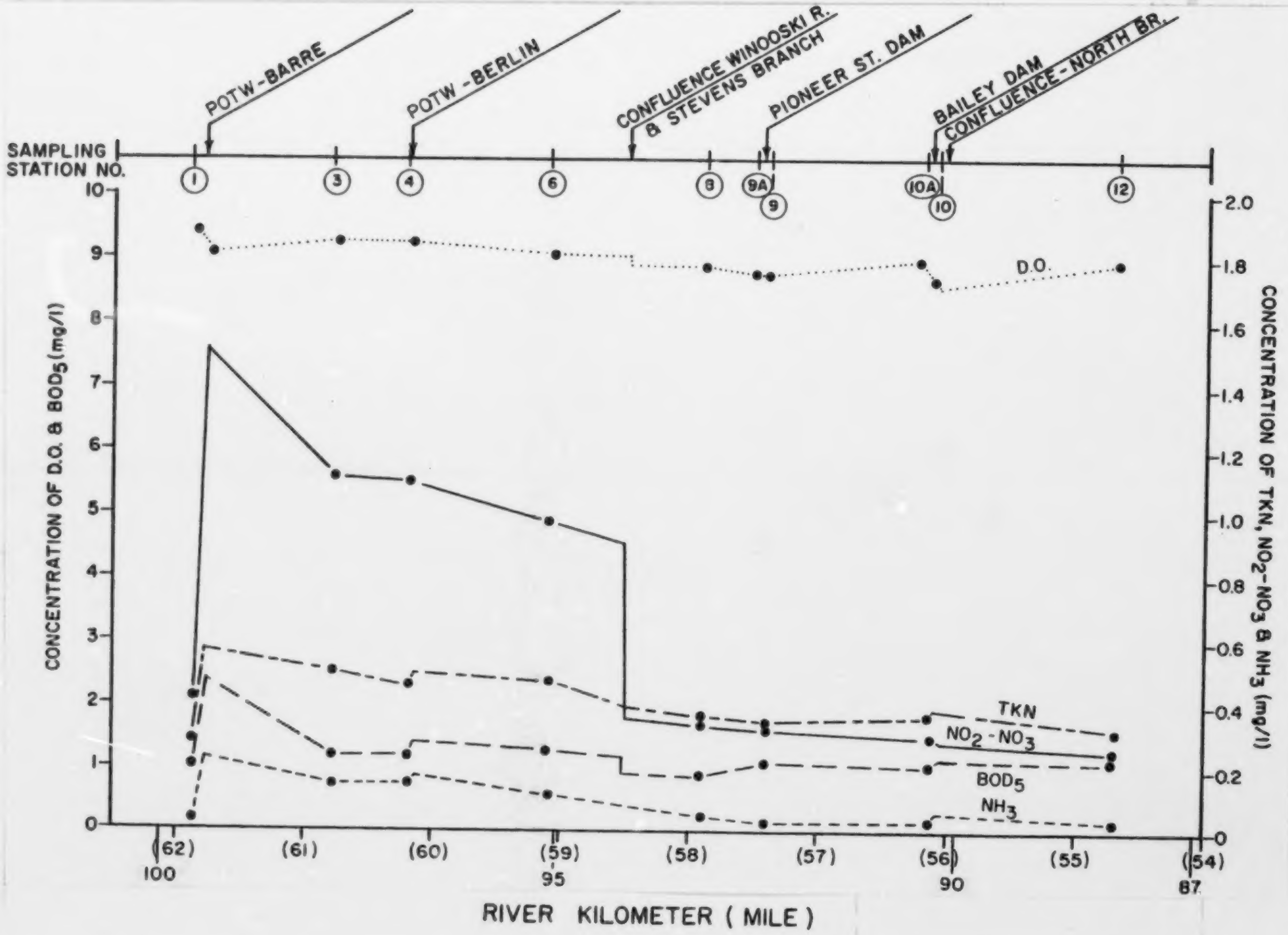

Figure 3-4. Profile of mean water quality parameter values (1979) (after Van Benschoten and Clarkson, 1979).

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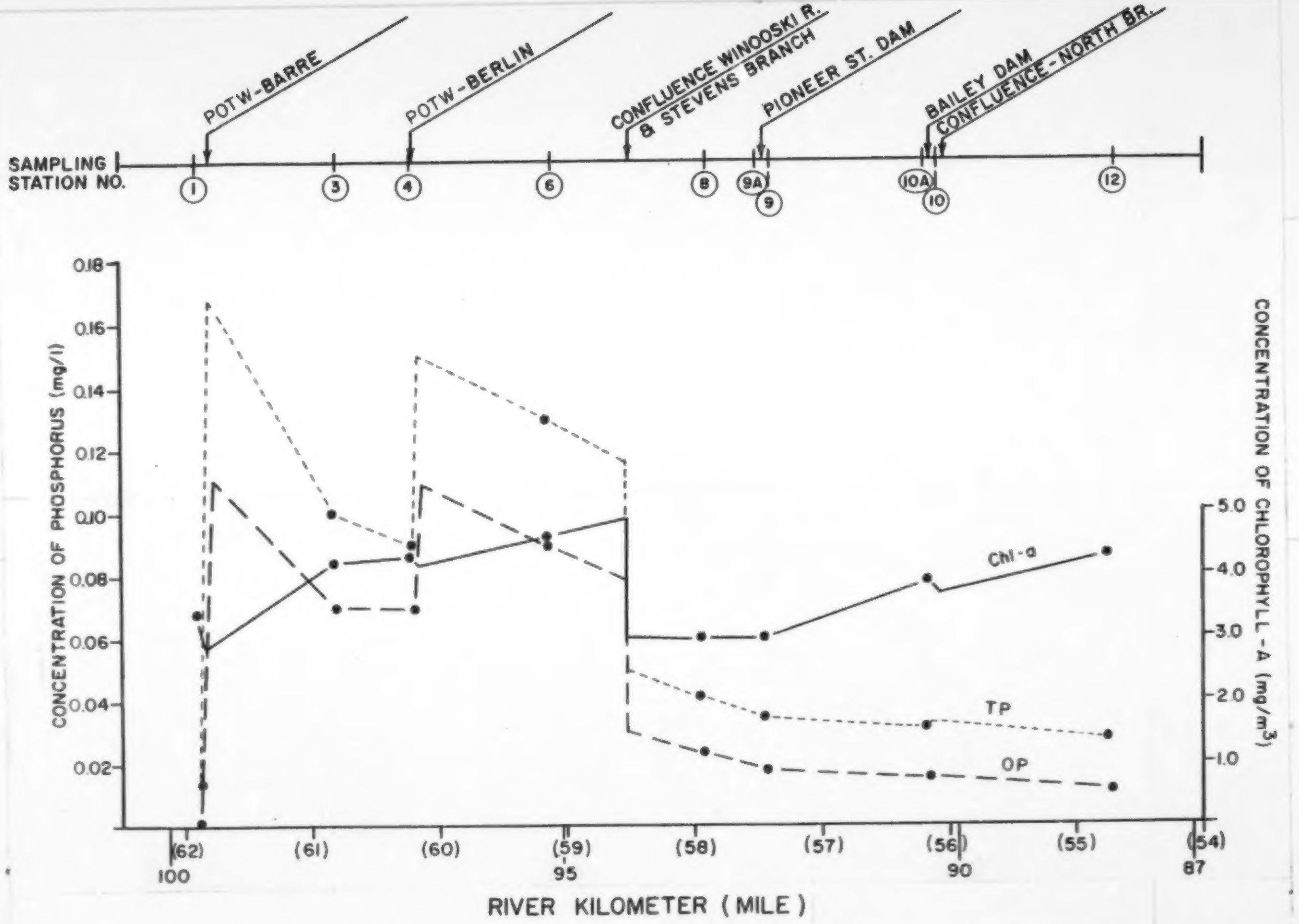

Figure 3-5. Profile of mean phosphorus and clorophyll-a values (1979) (after Van Benschoten and Clarkson, 1979).

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(PREVIOUSLY FIN. EPA FORM 247)
TYPING GUIDE SHEET

TABLE 3-11. PARAMETERS MEASURED AT EACH SAMPLING STATION

1978

Station Number	Temp. (00010)	DO (00300)	BOD_5 (00310)	NO_3-NO_2-N (00630)	NH_3-N (00610)	TKN (00625)
1	x	x	x	x	x	x
2			x	x	x	x
3	x	x	x	x	x	x
4	x	x	x	x	x	x
5			x	x	x	x
6	x	x	x	x	x	x
7	x	x	x	x	x	x
8	x	x	x	x	x	x
9A	x	x				
9	x	x	x	x	x	x
10A	x	x				
10	x	x	x	x	x	x
11	x	x	x	x	x	x
12	x	x	x	x	x	x

(Continued)

*Numbers given in parentheses below parameter names are the STORET codes for the parameters.

TABLE 3-11. (Concluded)

1979

Station Number	Parameters Measured*								
	Temp. (00010)	DO (00300)	BOD_5 (00310)	NO_3-NO_2-N (00630)	NH_3-N (00610)	TKN (00625)	O-P (00671)	T-P (00665)	CHL-a (32209)
1	x	x	x	x	x	x	x	x	x
2			x	x	x	x	x	x	
3	x	x	x	x	x	x	x	x	x
4	x	x	x	x	x	x	x	x	x
5		x	x	x	x	x	x	x	
6	x	x	x	x	x	x	x	x	x
7	x	x	x	x	x	x	x	x	x
8	x	x	x	x	x	x	x	x	x
9A	x	x							
9	x	x	x	x	x	x	x	x	x
10A	x	x							
10	x	x	x	x	x	x	x	x	x
11	x	x	x	x	x	x	x	x	x
12	x	x	x	x	x	x	x	x	x

*Numbers given in parentheses below parameter are the STORET codes for the parameters.

These parameters were measured every two to five hours during the intensive surveys, and the complete collection of data values is given in the computer data set. The parameters for each station were measured at twelve time intervals during the 1978 survey and at eighteen time intervals during the 1979 survey.

3-4-4. Sampling Techniques

This report sub-section was abstracted directly from the Vermont State Agency of Environmental Conservation report "Upper Winooski River Wasteload Allocation Study Part A: Report of Data," by Van Benschoten and Clarkson, 1979.

Collection Methods--

River and wastewater sampling runs commenced at 8:00 a.m. in 1978 and 8:00 p.m. in 1979 on the first day and continued at four hour intervals throughout the study period. A description and map of sampling locations are presented in Table 3-1 and Figure 3-1, respectively.

Sample bottles were acid washed in the laboratory and rinsed with distilled water. Prior to the collection of river water or POTW effluent, bottles were rinsed again with the field sample.

All stream samples were taken from the main current in order to obtain representative, well mixed samples. Except for those samples collected from bridges, the collection of chemistry samples was accomplished either by means of a long handled dip sampler or by filling sample bottles by hand from the streambank, depending on stream flow characteristics. Samples from bridges were collected using a standard Kemmerer water sampler.

Water samples for dissolved oxygen were collected using either the dip sampler or Kemmerer in the manner described by Welch (1948).

Effluent samples from POTW's were unchlorinated and collected either by a dip sampler (not the same one used for the river water samples) or by hand. At the Barre POTW a composite sample of the effluent was collected from each of the two clarifiers.

Samples were delivered to the laboratory within several hours of collection. For quality control purposes twenty percent true duplicates were collected.

Temperature--

Temperature in the streams was measured in situ using mercury thermometers calibrated from -20° to 100°C with 1°C subdivisions. The thermometers were standardized against a National Bureau of Standards thermometer for temperatures obtained during stream measurements.

Dissolved Oxygen--

Dissolved oxygen was determined as specified in *Standard Methods for the Examination of Water and Wastewater* (APHA, 1975) using the azide modification of the Winkler method.

Biochemical Oxygen Demand (BOD)--

Biochemical Oxygen Demand was determined as specified in Section 507 of *Standard Methods for the Examination of Water and Wastewater* (APHA, 1976), except for the following changes and modifications.

1. Effluent samples were analyzed using two dilutions per sample which were chosen on the basis of past data. River samples were analyzed without dilution and nutrients were added directly to the samples in the concentration of 1 mg/l.

2. All samples were incubated within 8 hours of collection at 20°C ± 1°C.

3. All dissolved oxygen analyses for BOD determinations were done using the azide modification of the Winkler method.

Quality control consisted of glucose-glutamic acid standards seeded with POTW effluent. Approximately two such standards were prepared for each day of the study. Control blanks were run on all dilution water used in the studies.

Carbonaceous Biochemical Oxygen Demand (CBOD)--

Carbonaceous biochemical oxygen demand was determined using the chemical Allyl Thiourea (ATU) as a nitrification inhibitor. ATU has been shown to be effective in inhibiting nitrification while exerting little interference on carbonaceous deoxygenation (Stamer et al., 1979; Young, 1973).

The active concentration of ATU for the $CBOD_5$ test was 5 mg/l for POTW samples and 2 mg/l for river samples. For the long-term CBOD determinations on POTW samples an additional amount of ATU was added to the samples on day 10 to maintain a 5 mg/l active ATU concentration (C.T. Scott, USGS, Doraville, GA, personal communication, June 1979). The addition of NH_4Cl to the dilution water was eliminated due to the possible nitrogenous oxygen demand it may induce in sewage effluent samples.

All other procedures were the same as for biochemical oxygen demand.

Nitrogen--

The chemical analyses for nitrogen were determined in accordance with the procedures outlined in *Methods for Chemical Analysis of Water and Wastes* (EPA, 1979) except for the variations explained in the following descriptions of methods and quality control. All results of nitrogen determinations are expressed in mg/l as nitrogen.

Nitrate-Nitrite Nitrogen (NO_3-NO_2-N)--

Nitrate-nitrite was measured using a Technicon Autoanalyzer II according to the automated cadmium reduction method, except for the following differences in reagent preparation:

1. Ammonium chloride solution: 10 g of ammonium chloride were dissolved in alkaline distilled water (pH 8.5, adjusted by use of ammonium hydroxide). The solution was diluted to one liter, and 0.5 ml of Brij-35 was added.

2. Color reagent solution: To 1500 ml of distilled water, 200 ml of concentrated phosphoric acid and 20 g of sulfanilmide were added. After complete dissolution, 1.0 g of N-1-naphthylethylenediamine dihydrochloride was added. The solution was diluted to 2 liters and stored in a cool, dark place.

Quality control consisted of analyzing 20% of all samples in duplicate and including reagent blanks and standards in each autoanalyzer run.

Ammonia Nitrogen (NH_3-N)--

Ammonia was measured using a Technicon Autoanalyzer II according to the automated colorimetric phenate method except that the alkaline phenol reagent was modified by the addition of 36 g of sodium hydroxide instead of 32 g.

Quality control consisted of analyzing 20% of all samples in duplicate and including reagent blanks and standards in each autoanalyzer run.

Total Kjeldahl Nitrogen (TKN)--

Total Kjeldahl nitrogen was analyzed by the manual method using a micro-glassware system except for the following variations in the prescribed procedure:

1. Samples collected at river stations with low concentrations of TKN were digested in two successive 50 ml batches for a total aliquot of 100 ml.

2. The samples were distilled into 5 ml of 4% boric acid because the increased strength of the acid would result in better capture.

The resulting distillate was analyzed for ammonia nitrogen using Nesserlerization in 1978 and the Technicon Autoanalyzer II in 1979.

Quality control consisted of analyzing all samples in duplicate and reanalyzing, in duplicate, any sample which had poor replicates. Standards were run at least once every eight hour shift and reagent blanks were run every eight hour shift and after every reagent change. Both standards and blanks were taken through the entire digestion and distillation procedure.

Phosphorus--

The chemical analyses for phoshporus were determined using a Technical Autoanalyzer II in accordance with the colorimetric automated ascorbic acid method described in Methods for Chemical Analysis of Water and Wastes (EPA, 1979) except for the variations explained in the following descriptions of methods. All results of phosphorus determination are expressed in mg/l as phosphorus.

Quality control consisted of analyzing 20% of all samples in duplicate and including reagent blanks and standards in each autoanalyzer run.

Total Phosphorus (T-P)--

The entire total phosphorus sample bottle was placed directly in storage at room temperature until the analysis was performed. At that time, 2 g of ammonium persulfate diluted in 5 ml distilled water and 1.5 ml concentrated H_2SO_4 were added to each bottle containing a 200 ml sample or standard. The bottles were then heated for 55 minutes at 121°C, cooled to room temperature, and analyzed on the Technicon II.

Ortho-Phosphorus (O-P)--

The ortho-phosphorus samples were analyzed on the Technicon II without determining the pH as specified in EPA (1979).

Variability Analysis of Duplicate Samples--

The duplicate samples collected during the Upper Winooski and other wasteload allocation studies in 1978 and 1979 were analyzed to determine the variability in the water quality analysis results. The sources of variability may include (1) a sample collected from a river or POTW which was not representative, (2) poor sampling technique, or (3) variability due to the method of analysis.

Water quality analysis results generally demonstrate that as the mean value of duplicate samples increases, so too does the standard deviation. Therefore, in order to analyze similar populations, both the river data and POTW data were divided into various groups as shown in Table 3-12.

Each standard deviation reported in Table 3-12 is the square root of the mean variance of the duplicates in each particular group. This approach is considered to result in the best estimate of the variability. Any standard deviation which is based on less than ten duplicate samples should not be considered reliable.

The variability results for the POTW's on the Stevens Branch are limited but there are sufficient data on the river samples from the Upper Winooski studies to make some comparisons between the two years. The NO_3-NO_2-N analysis in 1979 appears to be more variable than in 1978, while the TKN variability is lower in 1978 than in 1979. The reasons for these differences are unknown. The DO and BOD_5 results are similar for both years.

TABLE 3-12. VARIABILITY ANALYSIS OF DATA (after Van Benschoten and Clarkson, 1979)

1978

Test	Sample	Upper Winooski River Data		All 1978 Data	
		Number Duplicates	Std. Dev. (mg/l)	Number Duplicates	Std. Dev. (mg/l)
DO	Rivers - all	29	0.08	259	0.15
BOD_5	Rivers - all	25	0.21	88	0.19
	0.1-1.0 mg/l	7	0.12	19	0.13
	1.1-2.0 mg/l	5	0.17	31	0.15
	2.1-4.0 mg/l	8	0.2	33	0.2
	4.1-6.5 mg/l	5	0.3	5	0.3
	POTW				
	1.0-10 mg/l	3	0.15	17	0.64
	11-30 mg/l	3	3.0	10	2.0
NO_2-NO_3	Rivers - all	25	0.010	89	0.016
	POTW - all	3	0.1	13	0.4
NH_3	Rivers - all	21	0.022	86	0.012
	0.004-0.10 mg/l	16	0.005	45	0.006
	0.10-0.75 mg/l	5	0.04	41	0.02
	POTW				
	0.01-1.0 mg/l	1	0.001	10	0.052
	1.1-10 mg/l	3	0.4	11	0.4
TKN	Rivers - all	28	0.03	100	0.04
	POTW				
	1.1-10 mg/l	5	0.1	8	0.2
	11-50 mg/l	1	0.04	25	1.3

(Continued)

TABLE 3-12. (Concluded)

1979

Test	Sample	Upper Winooski River Data Number Duplicates	 Std. Dev. (mg/l)	All 1979 Data Number Duplicates	 Std. Dev. (mg/l)
DO	Rivers - all	38	0.10	80	0.11
BOD_5	Rivers - all	32	0.18	69	0.22
	0.1-1.0 mg/l	9	0.09	9	0.09
	1.1-2.0 mg/l	22	0.21	36	0.18
	2.1-5.0 mg/l	1	0.4	24	0.3
	POTW				
	0.5-10 mg/l	5	0.4	15	0.4
	11-35 mg/l	5	1.6	8	1.4
NO_2-NO_3	Rivers - all	32	0.021	64	0.016
	POTW				
	0.02-1.0 mg/l	3	0.04	12	0.06
	1.1-2.0 mg/l	4	0.2	20	0.2
NH_3	Rivers - all	31	0.009	52	0.008
	0.003-0.100 mg/l	12	0.009	33	0.006
	0.10-0.40 mg/l	19	0.01	19	0.01
	POTW				
	0.01-1.0 mg/l	2	0.02	13	0.01
	1.1-10 mg/l	6	0.3	12	1.1
TKN	Rivers - all	33	0.06	72	0.05
	POTW				
	0.05-1.0 mg/l	1	0.08	7	0.05
	1.1-10 mg/l	7	0.4	10	0.5
O-P	Rivers - all	37	0.002	70	0.002
	0.003-0.020 mg/l	16	0.001	49	0.001
	0.02-0.12 mg/l	21	0.002	21	0.002
	POTW				
	0.009-1.0 mg/l	3	0.07	6	0.05
	1.1-5.0 mg/l	5	0.06	23	0.06
T-P	Rivers - all	34	0.004	45	0.005
	POTW - all	7	0.1	17	0.4
CHL-a	Rivers - all	35	0.4(mg/m^3)	67	1.6(mg/m^3)
	1-7 mg/m^3	35	0.4	36	0.4

3-5. COMPUTER DATA SET

The computer data set includes the water quality measured at the stations listed in Table 3-1. There were 12 measurements made at each station during 22-24 August, 1978, and 18 measurements were made at each station during the 9-12 July, 1979, survey. The parameters measured at each station during each survey are listed in Table 3-11.

3-6. REFERENCES

1. American Public Health Association et al., Standard Methods for the Examination of Water and Wastewater, 14th ed., APHA, Washington, D.C., 1975.

2. Carter, R.W., and Davidian, J., "General Procedure for Gaging Streams," in Techniques of Water Resources Investigation of the USGS, Book 3, Chapter A6, U.S. Government Printing Office, Washington, D.C., 1968.

3. Environmental Protection Agency, "Methods for Chemical Analysis of Water and Wastes," National Environmental Research Center, Cincinnati, OH, 1974.

4. Stamer, J.K., McKenzie, S.W., Cherry, R.N., Scott, C.T., and Stamer, S.L., "Methods of Ultimate Carbonaceous BOD Determination," Journal WPCF, Vol. 51, No. 5, May 1979, pp 918-925.

5. Van Benschoten, J., and Clarkson, B., "Upper Winooski River Wasteload Allocation Study Part A: Report of Data," State of Vermont Agency of Environmental Conservation, Montpelier, VT, December 1979.

6. Welch, P.S., Limnological Methods, Blakiston Co., Philadelphia, PA, 1948.

7. Young, J.C., "Chemical Methods for Nitrification Control," Journal WPCF, Vol. 45, No. 4, April 1973, pp. 637-646.

SECTION 4

CHATTAHOOCHEE RIVER

4-1. INTRODUCTION

The Chattahoochee River flows in a southwest direction from the Blue Ridge Mountains of North Georgia through Lake Sidney Lanier to West Point Lake on the Georgia-Alabama border. The river then defines the Georgia-Alabama border as it flows southwards through Lake Harding and Walter F. George Reservoir, eventually flowing into Lake Seminole on the Georgia-Florida border. The Chattahoochee has been extensively studied over the last decade, and there is a large amount of data from the river stored in the STORET data system. However, much of this information is unsuitable for modelling purposes because the measurements are too infrequent or are taken at stations spaced too far apart.

The data presented in this report are drawn from four intensive river surveys and a river quality modelling study by the USGS. The intensive surveys cover a 69 km (43 mi) section of the river from Atlanta downstream to Whitesburg, and were conducted during summer and fall in 1976 and 1977. This section of the river receives effluent from several STP's and runoff from urban and agricultural areas. There are 16 small tributaries to this section of the Chattahoochee.

4-2. SOURCE LITERATURE

In 1973 and 1974 Water Resources Engineers, Inc., prepared a series of reports for the EPA on data collection and mathematical modelling of the Chattahoochee and Flint River basins (Duke, 1973a, 1973b; Hauck et al., 1973; Johnson and Duke, 1974a, 1974b). However, this very broad-scale study spent considerable effort on modelling the reservoirs along the river, and there are some weaknesses in the data on the river segments. Consequently this report presents instead a series of four intensive water quality surveys performed during the summer and fall in 1976 and 1977. These quality surveys were part of a general effort by the USGS to study the section of the Chattahoochee that flows from Atlanta to Whitesburg. The USGS has issued reports on river flow and temperature regimes (Faye et al., 1978a), sediment loads and channel morphology (Faye et al., 1978b), an evaluation of point and non-point discharges and nutrient loads (Stamer et al., 1978), and a river quality modelling report (McCutcheon, 1982). These USGS studies are complemented by a joint EPA/USGS study on the impact of urban runoff on the Chattahoochee River and those of its tributaries which receive runoff from Atlanta (McConnell, 1980). The U.S. Army Corps of Engineers has also compiled a report covering the period of August 1 to October 27, 1974, which presents quality data for use with the WQRRS model (Willey and Huff, 1978). Another source of additional data is the Georgia Department of Natural

Resources Environmental Protection Division, which issues annual reports on water quality monitoring of Georgia streams. There is also an article by Miller and Jennings (1979) on modelling nitrogen and oxygen in the Chattahoochee River.

4-3. RIVER BASIN DESCRIPTION

4-3-1 Study Area

The section of the Chattahoochee River for which data are presented in this report is a 69.39 km (43.12 mi) segment from Atlanta downstream to a sampling station near Whitesburg. A map of the study area is shown in Figure 4-1, and the sampling stations shown on the map are identified in Table 4-1. The map covers a larger area than was included in this study, and the map and table include stations at which no data were collected in this study. However, the additional information on sampling station positions and USGS identification numbers may be of value to those who wish to access additional data from STORET.

Land use in the study area (Table 4-2) is about 59% forested, 14% rural and 27% urban (Stamer et al., 1978). The forested land includes deciduous and coniferous forests, wetlands and water, while the rural land includes cropland, pastureland, and confined feed-lot operations. The urban land includes residential, commercial and industrial uses. The topography of the area is characterized by low hill ridges separated by narrow valleys. Land uses in selected individual tributary basins are presented in Table 4-3, and a more detailed assessment of land uses and morphology may be obtained from the report by Faye et al. (1978b).

The studied section of the river has 16 tributaries, receives flow from 7 waste treatment facilities (WTF's), provides cooling water to the Atkinson-McDonough thermoelectrical generating station, and provides a municipal water supply for the City of Atlanta.

4-3-2 Hydrologic Data

River Flows--

The Chattahoochee River is regulated by a series of dams which are used for peak-power hydroelectricity generation. Buford Dam and Morgan Falls dam are upstream of the study area, and West Point Dam is downstream. The river flows show a regular weekly cycle of higher flows during the week and lower flows at the weekends because there is less peak-power generation over the weekends. This effect is most clearly seen at the upstream end of the study area; further downstream the pattern is sometimes obscured by variations in the inflows from the river's tributaries.

The Chattahoochee River is gaged at Atlanta, Fairburn, and Whitesburg, and the USGS has developed a flow model for the river (Faye et al., 1978a). The frequency distribution of flows at the Atlanta gage is shown in Figure 4-2.

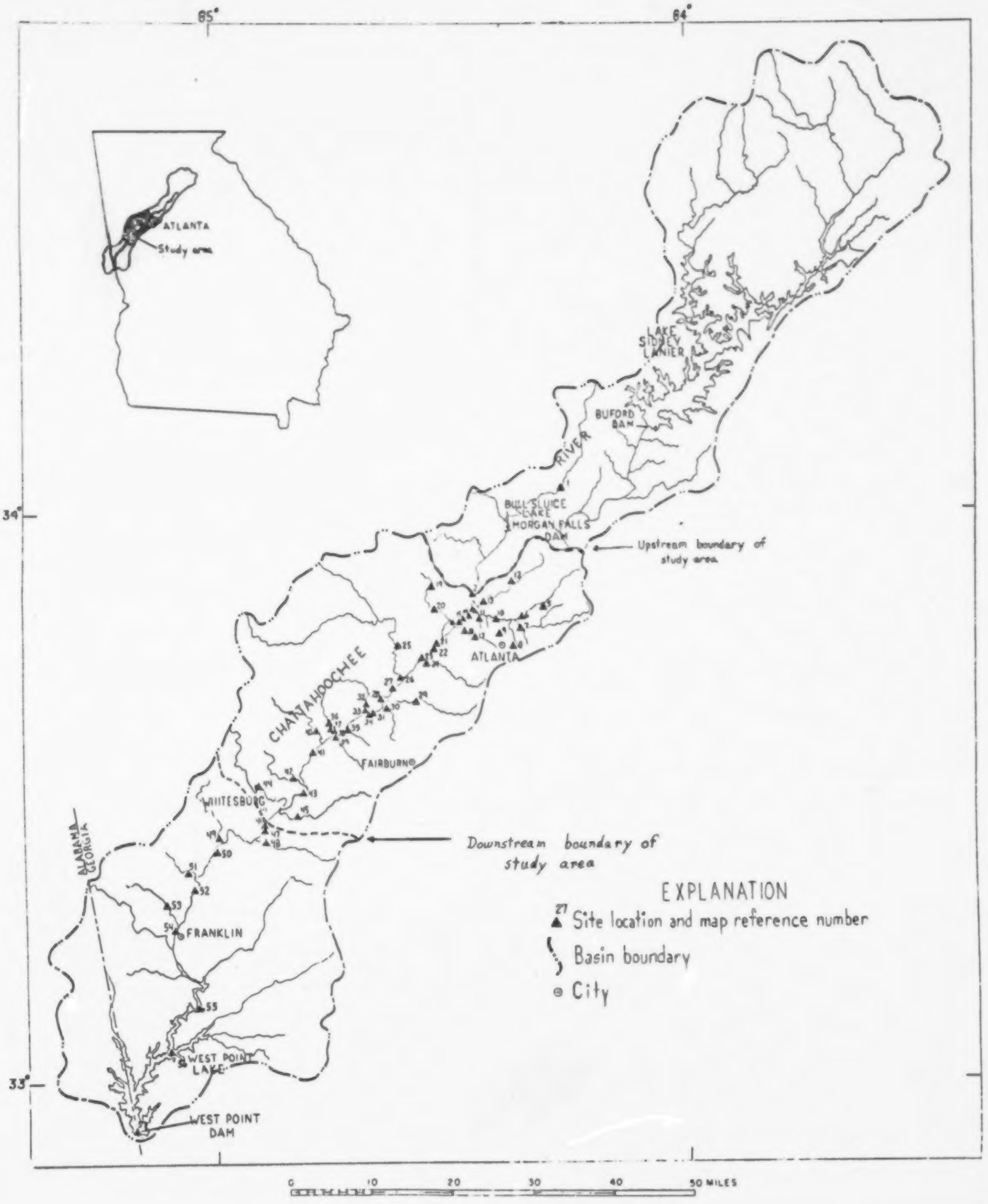
85°
84°
34°
33°
ATLANTA
Study area
LAKE
SIDNEY
LANIER
BUFORD
DAM
RIVER
BULL SLUICE
LAKE
MORGAN FALLS
DAM
Upstream boundary of
study area
ATLANTA
CHATTAHOOCHEE
FAIRBURN
WHITESBURG
Downstream boundary of
study area
ALABAMA
GEORGIA
FRANKLIN
WEST POINT
LAKE
WEST POINT
DAM
EXPLANATION
27
Site location and map reference number
Basin boundary
City
0
10
20
30
40
50 MILES

Figure 4-1. USGS sampling stations in the upper Chattahoochee River Basin (after Stamer et al., 1978).

TABLE 4-1. IDENTIFICATION OF UPPER CHATTAHOOCHEE SAMPLING STATIONS.[≠]

Map Reference No.	USGS Reference No.	Station Name	River Mile	River Kilometer
1	02335700	Big Creek near Alpharetta	317.37	510.76
2	02336000	Chattahoochee River at Atlanta	302.97	487.58
3	02336020	Chattahoochee River (Atlanta Intake) at Atlanta	300.62	483.80
4	02336021	Cobb Chattahoochee WTF near Atlanta	300.56	483.70
5	02336090	North Fork Peachtree Creek Tributary (Meadowcliff Drive) near Chamblee	------	------
6	02336104	North Fork Peachtree Creek at Buford Highway near Atlanta	------	------
7	02336250	South Fork Peachtree Creek at Atlanta	------	------
8	02336278*	Clear Creek at Piedmont Park at Atlanta	------	------
9	02336295*	Tanyard Branch at 26th Street extension at Atlanta	------	------
10	02336300	Peachtree Creek at Atlanta	300.52	483.64
11	02336313	Woodall Creek at Defoors Ferry Road at Atlanta	------	------
12	02336339	Nancy Creek Tributary near Chamblee	------	------
13	02336380	Nancy Creek at Randall Mill Road at Atlanta	------	------
14	02336450	R. M. Clayton WTF at Atlanta	300.24	483.19
15a	02336479	Plants Atkinson-McDonough at Atlanta (inlet)	299.19	481.50
15b	02336480	Plants Atkinson-McDonough at Atlanta (outfall)	299.11	481.37
16a	02336490	Chattahoochee River at SR 280 at Atlanta	298.77	480.2
16b	02336502	Chattahoochee River at I-285 Bridge at Atlanta	297.75	479.18
17	02336523	Hollywood Road WTF at Atlanta	------	------
18	02336526	Proctor Creek at SR 280 at Atlanta	297.50	487.78
19	02336537	Nickajack Creek (USAF Plant No. 6 outfall) near Smyrna	------	------
20	02336610	Nickajack Creek at Cooper Lake Road near Mableton	295.13	474.97
21	02336650	Chattahoochee River at SR 139 near Mableton	294.65	474.19
22	02336651	South Cobb Chattahoochee WTF near Mableton	294.28	473.60
23	02336653	Utoy Creek WTF near Atlanta	291.60	469.28
24a	02336724	Utoy Creek at SR 70 near Atlanta	291.57	469.24
24b	02336730	Chattahoochee River at Buzzard Roost Island near Mableton	290.57	467.63
25	02337000	Sweetwater Creek near Austell	288.58	464.42
26	†	Sweetwater Creek WTF near Austell	388.57	464.41
27	02337070	Chattahoochee River at SR 166 near Ben Hill	286.07	460.39
28	02337073	Camp Creek WTF near Atlanta	283.78	456.70
29	02337116	Camp Creek at Eron Road near Atlanta	283.54	456.31
30	02337160	Deep Creek at SR 70 near Tell	283.27	455.88

(continued)

TABLE 4-1 (concluded)

Map Reference No.	USGS Reference No.	Station Name	River Mile	River Kilometer
31	12337170	Chattahoochee River at SR 92 near Fairburn	281.88	453.64
32	02337200	Anneewakee Creek at SR 166 near Douglasville	281.47	452.98
33	†	Anneewakee Creek WTF near Douglasville	281.46	452.97
34	†	Three-river interceptor	281.45	452.95
35	02337233	Pea Creek at SR 70 near Palmetto	277.40	446.43
36	02337250	Bear Creek at SR 166 near Douglasville	275.95	444.10
37	†	Bear Creek (SR 166) WTF near Douglasville	275.94	444.08
38	02337260	Chattahoochee River (above Bear Creek) near Rico	275.81	433.87
39	02337320	Bear Creek at SR 70 near Rico	274.49	441.75
40	02337438	Dog River at SR 166 near Fairplay	273.46	440.09
41	02337445	Chattahoochee River (Capps Ferry Bridge) near Rico	271.19	436.44
42	02337454	Wolf Creek at SR 5 near Banning	267.34	430.24
43	02337457	Chattahoochee River at Hutcheson's Ferry near Rico	265.66	427.54
44	02337500	Snake Creek near Whitesburg	261.72	421.20
45	02337980	Cedar Creek at SR 70 near Roscoe	261.25	420.44
46	02338000	Chattahoochee River (U.S. Alt. 27) near Whitesburg	259.85	418.19
47	02337457	Plant Yates	259.70	417.95
48	02338160	Wahoo Creek at Arnco Mills	256.55	412.88
49	02338285	Whooping Creek near Lowell	250.87	403.74
50	?	Plant Wansley	249.20	401.05
51	02338320	Pink Creek near Centralhatchee	246.93	397.40
52	02338335	Chattahoochee River at Bush Head Shoals near Franklin	244.89	394.11
53	02338400	Centralhatchee Creek at U.S. 27 near Franklin	236.51	380.63
54	02338500	Chattahoochee River at U.S. 27 at Franklin	235.46	378.94
55	?	Chattahoochee River at SR 219 near LaGrange	221.26	356.08
56	?	Chattahoochee River at SR 109 near Abbottsford	210.67	339.04
57	?	West Point Lake at dam pool near West Point	202.36	325.67

≠ This Table composites information from Stamer et al. (1978), Faye et al. (1978), and personal communications with S.C. McCutcheon, USGS, Mississippi. It should be noted that USGS reports show discrepancies in the positions of some stations.

* Indicates a station where there is some doubt over the correct USGS reference number.

† Indicates a proposed WTF. At the time of writing, these stations do not have USGS station numbers.

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TABLE 4-2. LAND USE IN THE STUDY AREA (after Stamer et al., 1978).

Basin between:	Land Use: Urban (mi^2)	Urban Percent	Rural (mi^2)	Rural Percent	Forest (mi^2)	Forest Percent	Drainage Area (mi^2)
Atlanta to Fairburn	243	39.8	70.9	11.7	296	48.5	610
Fairburn to Whitesburg	24.1	6.5	62.0	16.8	284	76.7	370
Atlanta to Whitesburg	267.1	27.2	132.9	13.6	580	59.2	980

TABLE 4-3. LAND USE OF SELECTED TRIBUTARIES IN THE STUDY AREA (after Stamer et al., 1978).

1978).

Map reference number (Fig. 4-1)	Tributary	Land Use: Urban (mi^2)	Urban Percent	Rural (mi^2)	Rural Percent	Forest (mi^2)	Forest Percent	Drainage Area (mi^2)
1	Big Creek near Alpharetta[a]	5.94	8.0	26.1	36.0	40.0	56.0	72.4
5	North Fork Peachtree Creek Tributary (Meadowcliff Drive) near Chamblee	.27	84.0	.00	.0	.05	16.0	0.32
6	North Fork Peachtree Creek at Buford Highway near Atlanta	25.3	74.0	.04	.1	8.76	25.9	34.1
7	South Fork Peachtree Creek at Atlanta	22.9	77.1	.05	.2	6.71	22.7	29.6
8	Clear Creek at Piedmont Park at Atlanta	3.74	100.	.00	.0	.00	.0	3.74
9	Tanyard Branch at 26th Street extension at Atlanta	3.47	99.1	.00	.0	.03	.9	3.50
10	Peachtree Creek at Atlanta	69.5	80.0	.09	.01	17.2	19.9	86.8
11	Woodall Creek at Defoors Ferry Road at Atlanta	2.85	91.6	.00	.0	.26	8.4	3.11
12	Nancy Creek Tributary near Chamblee	1.72	52.9	.03	.9	1.50	46.2	3.25
13	Nancy Creek at Randall Mill Road at Atlanta	26.2	75.4	.28	.8	8.28	23.8	34.8
44	Snake Creek near Whitesburg	.40	1.1	5.75	15.5	30.8	83.4	37

[a] Station not in study area but included to represent quality characteristics of discharge from rural areas.

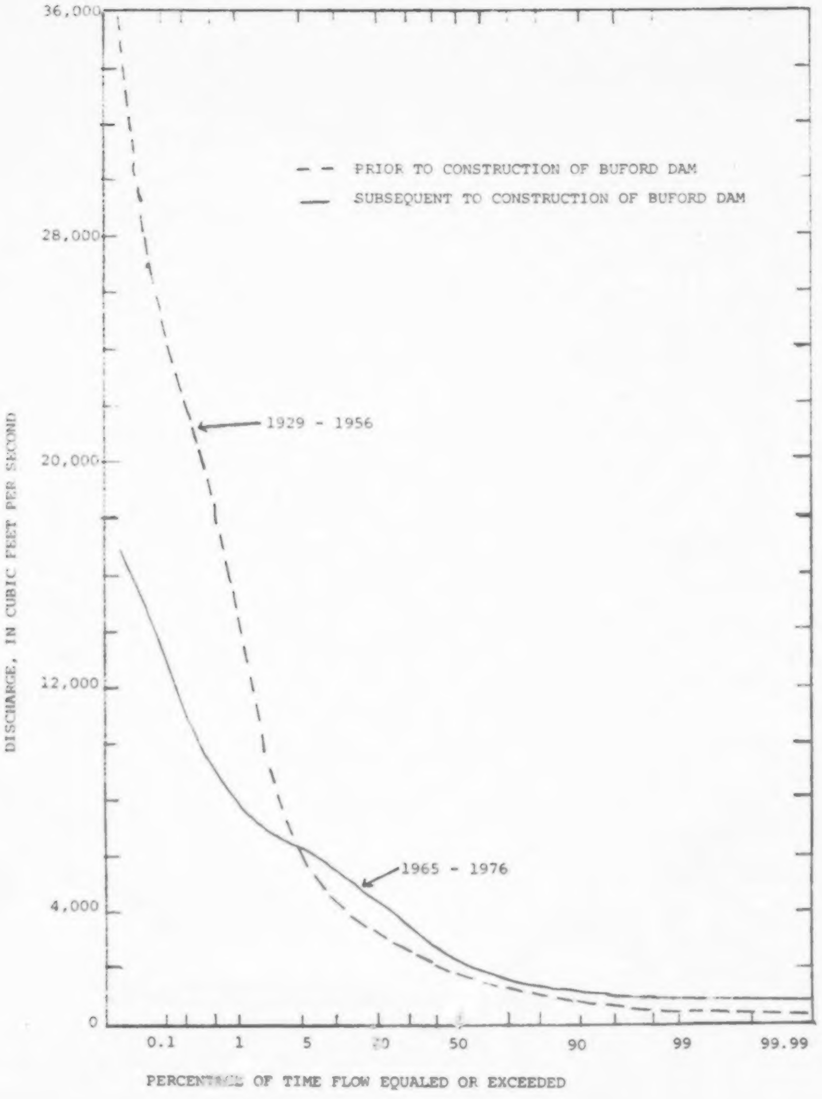

Figure 4-2. Frequency distribution of Chattahoochee River flows at the Atlanta gage (after Faye et al., 1978a).

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Point Inflows and Outflows--

The study section of the Chattachoochee River has 16 tributaries, receives flows from 7 WTF's, supplies cooling water to the Atkinson-McDonough power plants, and acts as a municipal water supply source for the City of Atlanta.

The tributary flow rates during the intensive surveys are given in Table 4-4. Some of the flow rates are based on flow measurements made during the intensive surveys, and others are estimates based on the USGS flow model for the Chattahoochee. With the exception of Nancy Creek, the flows are contained in the computer data set as input to the QUAL-II model. Where the flows were gaged, the measured flow rates are included in the USGS river sampling data which are also given in the computer data set.

The flow rates of the WTF's and the water withdrawals made for the City of Atlanta and the Atkinson-McDonough power plants are given in Table 4-5. The flow rates for all these facilities except Hollywood Road WTF and USAF Plant 6 are contained in the computer data set as QUAL-II model input data. The Hollywood Road WTF and USAF Plant 6 flows are not included because they do not flow directly into the Chattahoochee. Their flow rates are included in the flows of Proctor Creek and Nickajack Creek.

Non-Point Inflows--

The tributaries to the Chattahoochee River are formed by a series of small valleys which lie between hill ridges. As a result of this topography, almost all non-point flow enters the Chattahoochee by way of the tributaries, and very little enters the main river channel directly. Since all the tributary flows are included in the computer data set, it is possible to treat the tributaries as point sources to the river and neglect all direct non-point inflows to the river.

4-3-3 Hydraulic Data

River Cross Sections--

Most of the channel cross sections are approximately trapezoidal in shape, with steep banks and sand beds. However, shoals and rock beds are common near the Atlanta gage, downstream of the junction with Nickajack Creek, and from Capps Ferry Bridge to the Whitesburg gage (Faye et al., 1978a). Table 4-6 gives channel cross section coordinates at 41 locations between Atlanta and Whitesburg.

Stream Slope--

Figure 4-3 shows the river's thalweg altitude profile and the water surface profile under steady low flow conditions. The sharpest discontinuities in the thalweg profile occur at rivermiles 300.62 and 299.10 where weirs have been constructed to provide intake pools for the Atlanta Water Supply Faclity and the Atkinson-McDonough power plants. Smaller discontinuities occur where the river passes over bedrock controls or shoals.

Channel Roughness--

Maximum and minimum values of Manning's 'n' are given in Table 4-7. These values were derived by calibrating the USGS Chattahoochee flow model to match measured stage-flow relationships (Faye et al., 1978a, p 29).

TABLE 4-4. MEAN DAILY CHATTAHOOCHEE TRIBUTARY FLOWS DURING INTENSIVE SURVEYS (adapted from QUAL-II modelling by McCutcheon, 1982).

Map No.	Tributary	Survey Dates and Mean Tributary Flows (cfs)* 11-12 July 1976	30 Aug-1 Sept 1976	6-7 Sept 1976	31 May-2 June 1974
13	Nancy Creek**	22	--	--	21.5
10	Peachtree Creek**	68	37	12	87
18	Proctor Creek	7.5	6.1	6.1	7.4
20	Nickajack Creek	26	13	15	21
24	Utoy Creek	20	9.6	9.6	13.1
25	Sweetwater Creek	210	135	108	214
29	Camp Creek	20	10	10	19
30	Deep Creek	24	9.9	9.9	21
32	Anneewakee Creek	29	17	20	26
35	Pea Creek	15	4.1	10	26
36	Bear Creek at SR 166	23	11	15	20
39	Bear Creek at SR 70	25	6.2	15	16
40	Dog River	100	41	80	66
42	Wolf Creek	22	13	20	20.5
44	Snake Creek	64	53	60	41
45	Cedar Creek	40	14	20	30

* Where possible, the tributary flows are based on measured values which are given in the computer data set. Where no measurements were taken, the flows are based on estimates.

** The values given for Nancy Creek are from USGS sampling measurements, not QUAL-II input by McCutcheon. Nancy Creek joins Peachtree Creek very near to the Chattahoochee River, and the Peachtree Creek flows here represent the sum of Nancy Creek flows at station 02336380 and Peachtree Creek flows at station 02336300.

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TABLE 4-5. MEAN DAILY FLOWS OF MAN-MADE POINT SOURCES AND WITHDRAWALS (adapted from QUAL-II modelling study by McCutcheon, 1982)

		Survey Dates and Mean Tributary Flows (cfs)*			
Map No.	Tributary	11-12 July 1976	30 Aug-1 Sept 1976	6-7 Sept 1976	31 May-2 June 1974
3	Atlanta Municipal Water Withdrawal	-140	-140	-140	0
4	Cobb Chattahoochee WTF	15	12	4.8	13
14	R. M. Clayton WTF	130	77	130	150
15a	Plants Atkinson-McDonough (inlet)	-593	-593	-593	-354
15b	Plants Atkinson-McDonough (outfall)	593	593	593	354
17	Hollywood Rd. WTF		2.3**		--
19	USAF Plant No. 6 outfall		2.6**		--
22	South Cobb Chattahoochee WTF	17	13	44	15
23	Utoy Creek WTF	17	19	20	18
28	Camp Creek WTF	20	10	2.1	9

* Flows are based on monthly operator records.

** Mean daily flows for 1976 from Stamer et al. (1978). Data not included in computer data set.

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TABLE 4-6. CHANNEL CROSS SECTION COORDINATES (after Faye et al., 1978).

River mile 302.97

Horizontal distance (ft)	Altitude (ft)
20.0	767.0
40.0	762.0
55.0	760.5
70.0	755.3
85.0	751.9
100.0	750.7
115.0	750.9
130.0	749.7
145.0	749.5
160.0	749.6
170.0	748.1
180.0	748.4
190.0	747.4
200.0	747.4
210.0	747.8
220.0	749.4
230.0	750.3
240.0	749.7
250.0	747.9
260.0	747.7
270.0	747.9
280.0	749.0
290.0	750.8
300.0	751.3
310.0	753.1
320.0	756.8
330.0	766.8

River mile 302.38

Horizontal distance (ft)	Altitude (ft)
0	766
10	761
20	756
22	752
30	748
50	750
100	747
200	748
300	748
400	751
430	752
500	753
520	756
540	761
560	766

River mile 302.05

Horizontal distance (ft)	Altitude (ft)
0.0	761.5
14.0	752.6
40.0	746.5
100.0	743.4
140.0	747.1
200.0	747.7
220.0	746.8
244.0	752.6
264.0	762.3

River mile 300.98

Horizontal distance (ft)	Altitude (ft)
0.0	761.4
14.0	752.0
21.0	747.1
29.0	747.0
50.0	746.0
70.0	746.0
80.0	741.0
100.0	739.0
150.0	739.6
190.0	742.0
200.0	744.4
236.0	752.0
255.0	762.7

River mile 300.62

Horizontal distance (ft)	Altitude (ft)
0	760
42	755
62	750
82	748
100	746
120	745
160	745
200	745
240	745
280	745
320	746
340	748
360	750
373	755
386	760

River mile 300.44

Horizontal distance (ft)	Altitude (ft)
364.0	762.6
381.0	760.2
409.0	748.9
425.0	748.3
439.0	740.1
459.0	740.8
510.0	740.8
559.0	739.3
610.0	739.0
659.0	739.0
687.0	749.7
705.0	761.8

River mile 300.29

Horizontal distance (ft)	Altitude (ft)
23.0	776.0
66.0	763.0
82.0	761.2
103.0	750.9
118.0	743.3
169.0	741.0
216.0	735.0
265.0	735.2
309.0	750.9
325.0	760.2
405.0	764.2

River mile 299.94

Horizontal distance (ft)	Altitude (ft)
210.0	756.8
240.0	742.2
260.0	734.0
280.0	731.2
300.0	731.2
320.0	734.7
340.0	734.9
360.0	734.5
380.0	735.7
400.0	734.1
410.0	740.2
430.0	760.3

(continued)

TABLE 4-6 (continued)

Horizontal distance (ft)	Altitude (ft)
River mile 299.56	
26.0	765.7
75.0	738.1
125.0	733.7
175.0	733.5
225.0	733.9
256.0	738.5
280.0	752.9
325.0	754.9
425.0	753.9
460.0	762.4
River mile 299.20	
-20.0	754.5
0.0	741.4
15.0	735.9
55.0	733.1
105.0	733.9
125.0	735.6
175.0	729.6
185.0	730.8
210.0	755.5
River mile 299.10	
0	754
20	744
35	740
60	739
100	739
150	740
200	741
214	744
233	755
River mile 298.93	
0.0	755.1
20.0	745.5
35.0	738.5
45.0	733.0
60.0	736.3
100.0	735.2
150.0	735.4
River mile 298.93 (continued)	
200.0	736.4
214.0	744.5
233.0	756.0
85.0	756.7
130.0	736.2
140.0	741.1
150.0	739.8
160.0	735.7
170.0	734.3
180.0	733.4
190.0	734.1
200.0	734.4
210.0	735.4
220.0	733.7
230.0	733.6
240.0	734.4
250.0	735.1
260.0	735.3
270.0	737.1
280.0	737.1
290.0	738.3
300.0	737.7
310.0	739.1
322.6	741.1
332.0	744.2
373.0	754.7
River mile 298.10	
-40.0	762.5
-29.0	757.0
0.0	755.0
50.0	731.8
107.0	733.4
139.0	733.3
200.0	735.4
218.0	755.8
223.0	740.5
260.0	760.1
290.0	764.4
River mile 297.86	
0.0	753.6
15.0	743.9
30.0	737.9
50.0	735.4
100.0	736.9
150.0	736.0
200.0	736.2
214.0	743.9
222.0	752.2
River mile 297.73	
74.0	757.7
130.0	751.3
145.0	741.6
160.0	735.7
180.0	733.7
230.0	734.9
280.0	734.7
300.0	733.8
315.0	736.5
326.0	741.7
347.0	755.2
367.0	759.2
River mile 297.06	
0.0	754.0
15.0	745.8
16.0	739.3
30.0	734.8
50.0	734.8
77.0	734.5
90.0	732.3
100.0	735.8
150.0	734.1
165.0	736.0
182.0	739.3
183.0	746.2
195.0	751.2

(continued)

TABLE 4-6 (continued)

Horizontal distance (ft)	Altitude (ft)
River mile 296.60	
140.0	750.3
152.0	742.9
165.0	735.9
190.0	736.4
240.0	735.1
290.0	735.5
340.0	735.2
355.0	736.0
368.0	743.8
388.0	751.2
River mile 295.30	
0.0	752.3
25.0	740.5
40.0	731.9
100.0	731.8
150.0	732.0
200.0	732.4
240.0	732.8
254.0	740.5
285.0	749.9
River mile 294.70	
0.0	769.5
45.0	755.9
100.0	752.0
153.0	745.0
165.0	738.3
200.0	738.0
248.0	735.8
299.0	727.0
367.0	733.8
398.0	755.3
423.0	757.8
450.0	768.7
River mile 293.92	
55.0	753.5
86.0	742.0
100.0	731.6
197.0	729.0
300.0	730.9
311.0	742.0
330.0	749.4
400.0	750.4
River mile 293.10	
0.0	751.9
15.0	739.3
16.0	733.3
30.0	731.1
36.0	727.8
50.0	729.2
100.0	728.1
104.0	729.3
150.0	727.6
167.0	726.6
180.0	729.2
199.0	733.2
200.0	739.3
215.0	750.3
River mile 292.19	
400.0	751.6
420.0	737.9
437.0	729.8
450.0	728.2
470.0	725.2
494.0	726.2
510.0	726.1
560.0	727.4
575.0	723.7
586.0	729.5
606.0	737.9
659.0	755.6
River mile 290.54	
-20.0	746.4
0.0	741.7
10.0	737.0
20.0	730.5
30.0	724.7
50.0	727.1
100.0	725.5
153.0	728.0
170.0	722.7
180.0	730.5
195.0	744.1
River mile 287.86	
-9.0	744.6
2.0	741.5
16.0	732.0
28.0	725.1
40.0	721.8
50.0	724.6
100.0	724.8
150.0	723.8
200.0	724.1
210.0	723.8
216.0	725.9
233.0	732.0
249.0	741.9
270.0	744.2

(continued)

TABLE 4-6 (continued)

Horizontal distance (ft)	Altitude (ft)
River mile 286.96	
0.0	742.1
15.0	729.8
20.0	727.1
30.0	725.8
50.0	722.3
100.0	721.9
150.0	722.1
200.0	721.8
245.0	727.1
255.0	729.8
270.0	741.2
River mile 286.07	
220.0	739.9
248.0	718.0
270.0	719.9
320.0	720.8
370.0	721.1
420.0	720.0
435.0	721.0
482.0	738.9
River mile 284.32	
0.0	735.1
5.0	720.7
30.0	717.8
80.0	718.2
95.0	716.7
121.0	718.5
150.0	719.2
160.0	719.2
190.0	720.7
195.0	739.4
River mile 281.79	
20.0	743.9
50.0	738.2
80.0	737.4
110.0	736.3
140.0	734.6
170.0	734.3
River mile 281.79 (continued)	
200.0	729.8
220.0	719.5
245.0	715.0
270.0	714.1
290.0	716.5
310.0	715.3
330.0	714.7
334.0	714.9
337.0	716.3
340.0	716.8
355.0	716.8
370.0	716.9
390.[illegible]	716.8
410.[illegible]	717.1
430.0	718.0
450.0	722.3
470.0	730.4
500.0	736.5
530.0	739.2
565.0	741.3
580.0	743.8
River mile 281.07	
0.0	737.9
12.0	720.2
20.0	722.5
40.0	710.2
70.0	716.1
100.0	714.5
150.0	714.8
200.0	713.1
227.0	720.2
235.0	735.6
River mile 279.99	
0.0	733.6
5.0	722.1
23.0	714.3
35.0	711.7
60.0	714.7
100.0	715.5
200.0	715.6
210.0	716.2
225.0	722.1
230.0	735.1
River mile 277.95	
0.0	734.0
10.0	720.8
20.0	710.8
30.0	708.3
60.0	710.8
180.0	710.8
210.0	711.7
235.0	711.8
240.0	713.8
245.0	714.7
254.0	720.8
264.0	727.8
354.0	729.3
River mile 274.12	
-65.0	732.0
-48.0	728.5
0.0	725.4
20.0	713.7
100.0	713.3
150.0	712.9
200.0	712.7
260.0	711.2
266.0	719.9
271.0	726.8
300.0	732.2

(continued)

TABLE 4-6 (concluded)

Horizontal distance (ft)	Altitude (ft)
River mile 272.20	
-10.0	727.2
3.0	713.2
8.0	710.5
30.0	712.1
80.0	710.9
120.0	711.1
140.0	710.8
180.0	711.3
200.0	712.5
230.0	712.8
250.0	713.2
260.0	727.5
River mile 271.22	
0.0	740.5
30.0	728.5
44.0	728.3
50.0	718.3
51.0	713.5
69.0	710.7
80.0	710.5
100.0	709.7
150.0	711.5
200.0	712.4
250.0	711.0
300.0	710.2
330.0	709.3
352.0	713.5
353.0	718.3
365.0	724.8
376.0	725.7
406.0	739.5
River mile 270.86	
0.0	716.5
20.0	712.5
40.0	708.0
60.0	709.5
80.0	710.0
100.0	710.0
120.0	710.0
140.0	710.5
River mile 270.86 (continued)	
160.0	711.5
180.0	709.0
200.0	707.3
220.0	709.5
240.0	710.0
260.0	710.0
280.0	710.5
286.0	711.0
291.0	716.5
River mile 270.43	
-86.0	719.3
0.0	715.5
10.0	707.8
25.0	701.5
76.0	702.4
125.0	701.5
165.0	700.9
240.0	700.4
246.0	707.8
253.0	716.6
River mile 268.34	
800.00	710.8
900.0	707.3
910.0	704.1
925.0	701.8
975.0	701.6
1000.0	700.6
1050.0	698.3
1100.0	698.6
1150.0	699.7
1210.0	702.4
1215.0	704.1
1235.0	708.2
1275.0	712.7
River mile 266.02	
0.0	702.5
14.0	698.1
30.0	692.1
80.0	692.7
120.0	693.1
170.0	693.4
210.0	692.9
222.0	698.1
244.0	704.6
River mile 263.62	
0.0	700.2
10.0	690.2
33.0	684.9
110.0	687.2
200.0	686.4
224.0	684.9
229.0	686.4
250.0	690.1
264.0	697.6
River mile 259.87	
-20.0	699.6
0.0	692.6
20.0	684.1
40.0	684.0
57.0	684.4
61.0	681.6
80.0	683.8
100.0	681.8
120.0	679.6
140.0	678.6
157.0	677.1
161.0	676.5
180.0	680.1
200.0	680.6
220.0	680.1
240.0	679.6
257.0	679.6
261.0	682.6
280.0	684.0
300.0	689.1
310.0	691.6
330.0	699.6

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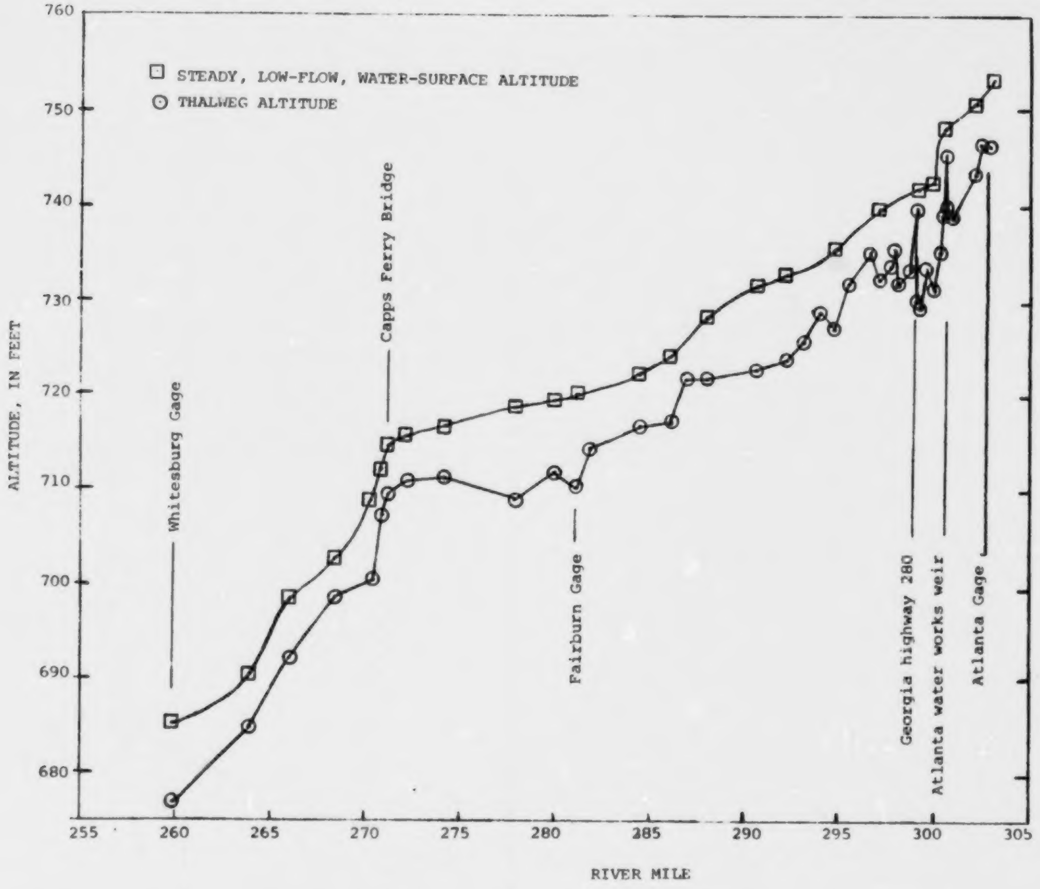

Figure 4-3. Thalweg and low-flow profile of the Chattahoochee River - Atlanta to Whitesburg (after Faye et al., 1978a).

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TABLE 4-7. CHANNEL ROUGHNESS AND BARRIER HEIGHT VALUES (after Faye et al., 1978).

	Manning's n		Effective barrier height
River mile	Maximum	Minimum	(ft)
302.79	0.057	0.032	50
302.38	.055	.040	45
302.05	.066	.029	40
300.98	.050	.034	30
300.62	.080	.056	60
300.44	.051	.040	20
300.29	.039	.039	15
299.94	.039	.021	15
299.56	.040	.040	15
299.20	.042	.024	10
299.10	.050	.021	20
298.93	.038	.031	25
298.77	.038	.030	15
298.10	.033	.024	25
297.86	.033	.026	25
297.73	.031	.024	25
297.06	.034	.028	20
296.60	.034	.025	20
295.30	.035	.026	15
294.70	.035	.028	15
293.92	.034	.023	10
293.10	.039	.039	15
292.19	.042	.021	30
290.54	.047	.038	25
287.86	.041	.026	20
286.96	.038	.038	15
286.07	.025	.025	30
284.32	.027	.020	50
281.79	.030	.025	40
281.07	.025	.021	40
279.99	.027	.024	40
277.95	.025	.021	50
274.12	.033	.026	60
272.20	.028	.014	40
271.22	.028	.026	40
270.86	.058	.049	40
270.43	.052	.037	40
268.34	.080	.058	60
266.02	.080	.060	50
263.62	.040	.034	40
259.85	.040	.030	25

Flow Stages--

Figures 4-4 and 4-5 show rating curves for the Chattahoochee River at the Fairburn and Whitesburg gages. These rating curves are computed by the USGS flow model for the river. The flow model matches measured discharges at the gages very closely, though it shows some phase shifts because it uses a single rating curve instead of following the hysteresis loop of actual flow-stage relationships.

Table 4-8 gives water surface elevations at specific discharge rates for several river locations, and Table 4-9 gives reach-averaged depths and widths with measured river discharge rates.

Average Flow Velocities--

Average flow velocities under low flow conditions may be derived from Table 4-9. The table gives time of travel information with measured river discharge rate under steady low flow conditions. The times of travel are based on hydraulic calculations, not dye studies.

4-3-4 Climatological Data

Climatological data are not presented in this section, and must be obtained from weather stations in the study area. Data from NOAA weather stations may be obtained from the NOAA publication, "Climatological Data for Georgia".

4-3-5 Sampling Techniques

Flow Rates--

The USGS maintains flow gages on the Chattahoochee River near Atlanta, Fairburn, and Whitesburg. Tributary flows were gaged using portable instruments, and WTF flows were calculated from monthly operator records.

Flow Velocities--

Average flow velocities in the river must be calculated from time of travel data for 31 reaches in the study area presented by McCutcheon (1982). The time of travel data are based on hydraulic calculations which match the river's observed flow rate and stage heights, and they have not been verified with dye studies.

Channel Cross Sections--

The cross sectional coordinates of the river channel were measured by the USGS and the U.S. Army Corps of Engineers.

4-4. RIVER QUALITY DESCRIPTION

4-4-1 Major Pollution Sources

Point Sources--

The Chattahoochee River receives effluent from 7 WTF's and inflows from 16 tributaries. The positions of the sources are given in Table 4-1, and are shown in Figure 4-1.

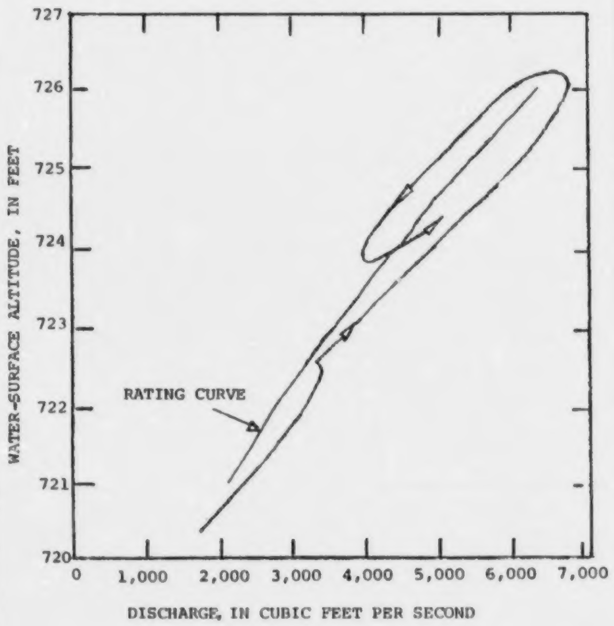

Figure 4-4. Computed rating curve for the Chattahoochee River near Fairburn (after Faye et al., 1978a).

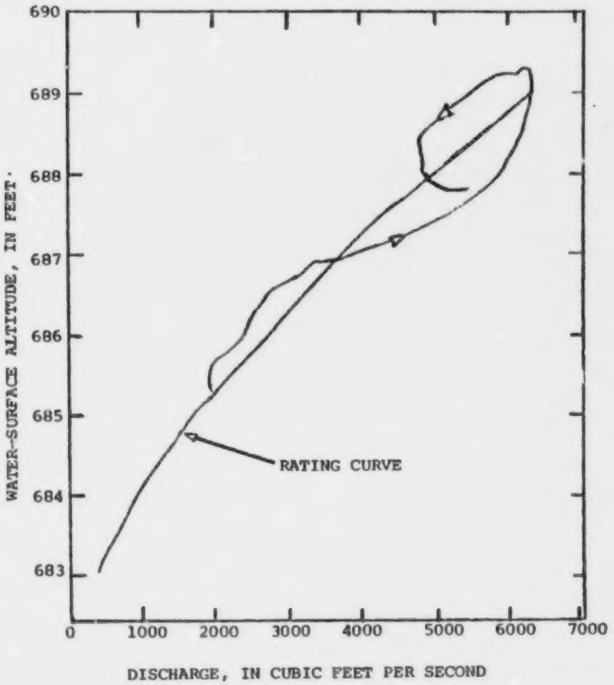

Figure 4-5. Computed rating curve for the Chattahoochee River near Whitesburg (after Faye et al., 1978a).

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TABLE 4-8. WATER-SURFACE ELEVATIONS AND DISCHARGE MEASUREMENTS ON THE CHATTAHOOCHEE RIVER (after McCutcheon, 1982).

Location	River Mile	Water-Surface Elevation ft above 1929 NGVD	River Discharge* ft^3/s
Atlanta gage	302.97	753.9	1140
Atlanta water treatment plant weir	300.62	748.0	995**
Power plant weir	299.11	742.4	1277†
State Route 280 Bridge	298.77	740.9	1277
State Route 139 Bridge	294.65	734.4	1288††
State Route 166 Bridge	286.07	724.4	1349‡
Fairburn‡‡	281.88	720.6	1770
		720.97	2020
Capps Ferry Bridge	271.19	715.00	2223
Whitesburg	259.85	685.59	2350

---

* Some tributary discharges were not available.

** Water plant withdrawal = 140 ft^3/s.

† South Cobb STP + Peachtree Ck. ≅ 142 ft^3/s, Clayton STP ≅ 140 ft^3/s.

†† Proctor Ck. ≅ 10 ft^3/s, Nickajack Ck. ≅ 30 ft^3/s.

‡ South Cobb STP + Utoy STP + Utoy Ck. ≅ 30 ft^3/s, Sweetwater Ck. ≅ 297 ft^3/s.

‡‡ Survey began at Atlanta gage and proceeded downstream to Capps Ferry Bridge where the survey stopped for nightfall and began anew the next morning. Discharge and water-surface elevation increased overnight.

Note: 1 mile = 1.61 kilometers, 1 ft^3/s = 0.028 m^3/s, and 1 foot = 0.3048 meters.

Data in this table were adapted from a written communication by Harvey Jobson, Hydrologist, USGS, Bay St. Louis, Miss.

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TABLE 4-9. REACH-AVERAGED DEPTHS, WIDTHS, TRAVEL TIMES, AND STEADY LOW FLOWS FOR THE CHATTAHOOCHEE RIVER* (after McCutcheon, 1982).

Tributary or Location	Beginning** River Mile	Cumulative Travel Time hrs.	Measured Discharge of Trib. or River ft^3/s	Depth ft	Width ft
Atlanta Gage	302.97	0	1248	4.25	234
Cobb Co. STP	300.56	3.45	16	4.02	236
Peachtree Ck.	300.52	3.52	37	4.32	236
Clayton STP	300.24	3.86	128	4.26	237
Power Plants	299.11	5.50	#	5.14	238
SR-280 Bridge	298.77	5.94	1288	4.24	238
I-285 Bridge	297.75	7.08	1429	5.12	239
Proctor Ck.	297.50	7.20	6	4.22	239
Nickajack Ck.	295.13	9.56	13	5.12	241
SR-139 Bridge	294.65	9.96	1448	4.25	242
South Cobb STP	294.28	10.30	13	5.09	242
Utoy STP	291.60	12.98	19	4.29	244
Utoy Ck.	291.57	13.01	10	5.18	244
CR at Buzzard Is.	209.57	13.65	1490	4.34	244
Sweetwater Ck.	288.58	15.73	130	5.14	246
SR-166 Bridge	286.07	18.33	1620	5.09	248
Camp Ck. STP	283.78	20.78	7	5.06	250
Camp Ck.	283.54	21.06	10	5.10	250
Deep Ck.	283.27	21.35	10	5.11	250
Fairburn (SR-92)	281.88	22.75	1646	5.13	251
Anneewakee Ck.	281.47	23.19	17	5.08	252
Pea Ck.	277.40	27.53	4	5.16	255
Upper Bear Ck.	275.95	29.00	11	5.02	256
CR near Bear Ck.	275.81	29.20	1678	5.19	257
Lower Bear Ck.	274.49	30.66	6	5.00	257
Dog River	273.46	31.80	42	5.20	258
Capps Fy. Bridge	271.19	34.03	1726	5.20	260
Wolf Ck.	267.34	38.12	13	5.10	263
CR at Hutcheson's Fy.	265.66	39.40	1739	5.19	264
Snake Ck.	261.72	42.56	53	5.01	268
Cedar Ck.	261.25	42.96	14	5.39	268
CR at Whitesburg##	259.85	44.28	1799	5.03	269

*Interpreted from office notes furnished by USGS, Doraville, GA, District Office.
**Faye et al. (1978a), Stamer et al. (1978), and field notes, disagree on exact river locations; river mile designations of Stamer and others are used.
#Discharge not measured.
##End of the study reach.

Note: 1 mile = 1.61 kilometers, 1 ft^3/s = 0.028 m^3/s, 1 foot = 0.3048 meters, SR is an abbreviation for State Route, CR is Chattahoochee River, Fy. is Ferry, STP is Sewage Treatment Plant, and Ck. is Creek.

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Information on the loading rates to the river from these sources is included in the QUAL-II input data in the computer data set. The parameters specified at the headwaters and point inflows are given in Table 4-10.

TABLE 4-10. MODELLING PARAMETERS SPECIFIED FOR CHATTAHOOCHEE RIVER HEADWATERS AND POINT SOURCES.

Parameter	Units
Point load inflow or withdrawal	cfs
Temperature	°F
D.O. concentration	mg/l
BODu concentration	mg/l
Ammonia as N concentration	mg/l
Nitrite as N concentration	mg/l
Nitrate as N concentration	mg/l
Phosphate as P concentration	mg/l
Coliform	no./100 ml

Loading data from the tributaries and other point-sources are also contained in the USGS intensive survey data sets which are included in the computer data set. The number of samples taken at each station on each day during the intensive surveys is given in Table 4-11, and the parameters measured in each sample are given in Table 4-12.

An assessment of the nature and impact of the point sources may be obtained from the report by Stamer et al., (1978). The report by McConnell (1980) gives a detailed description of the nature and effects of urban runoff from Atlanta.

Non-Point Sources--

Almost all non-point discharges to the Chattahoochee River enter the river by way of its tributaries, so that it is possible to model the river by treating the tributaries as point sources and neglect all non-point sources that flow directly into the main channel. However, it may be of interest to consider the effects of the non-point inflows and compare them to the point loads.

McConnell (1980) presents information on non-point urban runoff from Atlanta. Stamer et al. (1978) also present information on non-point loads to the river, and a comparison of point and non-point loading rates drawn from this report is shown in Figure 4-6.

4-4-2 Biochemical Data

River Quality Sampling--

The USGS made 4 intensive surveys of the Chattahoochee River from the

TABLE 4-11. NUMBER OF SAMPLES MEASURED AT EACH STATION DURING INTENSIVE USGS SURVEYS.

USGS No.	Map No.	Name	Date of sampling and number of samples taken													
			76-07-11	76-07-12	76-08-28	76-08-29	76-08-30	76-08-31	76-09-05	76-09-06	76-09-07	76-09-08	77-05-30	77-05-31	77-06-01	77-06-02
02336000	2	Chattahoochee River at Atlanta	1	4	1	1	6	1	1	2	7	2	2	23	18	7
02336021	4	Cobb Chattahoochee WTF near Atlanta	-	-	-	-	1	-	-	-	1	-	5	10	12	-
02336300	10	Peachtree Creek at Atlanta	-	-	-	-	1	-	-	-	-	-	4	-	-	-
02236380	13	Nancy Creek at Randall Mill Road at Atlanta	-	1	-	-	-	-	-	-	-	-	4	-	-	-
02236450	14	R.M. Clayton WTF at Atlanta	-	-	-	-	1	-	-	-	1	-	5	10	11	-
02236480	15b	Plants Atkinson-McDonough at Atlanta (outfall)	-	-	-	-	5	-	-	-	1	-	3	9	10	-
02236490	16a	Chattahoochee River at SR 280 at Atlanta	-	2	-	-	5	-	-	-	6	-	2	22	18	7
02236526	18	Proctor Creek at SR 280 at Atlanta	-	1	-	-	-	1	-	-	-	-	6	-	-	-
02236610	20	Nickajack Creek at Cooper Lake Road near Mableton	-	1	-	-	-	1	-	-	-	-	2	2	-	-
02236650	21	Chattahoochee River at SR 139 near Mableton	-	8	-	-	5	-	-	-	7	-	2	16	13	6
02236651	22	South Cobb Chattahoochee WTF near Mableton	-	-	-	-	1	-	-	-	1	-	2	12	11	-
02236653	23	Utoy Creek WTF near Atlanta	-	-	-	-	1	-	-	-	1	-	3	11	11	-
02236724	24a	Utoy Creek at SR 70 near Atlanta	-	1	-	-	-	1	-	-	-	-	4	-	-	-
02236730	24b	Chattahoochee River at Buzzard Roost Island near Mableton	-	-	-	-	4	-	-	-	-	-	-	-	-	-
02237000	25	Sweetwater Creek near Austell	-	1	-	-	-	2	-	-	-	-	2	2	-	-
02237070	27	Chattahoochee River at SR 166 near Ben Hill	-	4	-	-	4	-	-	-	6	-	2	14	16	7
02237073	28	Camp Creek WTF near Atlanta	-	-	-	-	1	-	-	-	1	-	3	8	12	-

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TABLE 4-11 (concluded)

USGS No.	Map No.	Name	Date of sampling and number of samples taken 76-07-11	76-07-12	76-08-28	76-08-29	76-08-30	76-08-31	76-09-05	76-09-06	76-09-07	76-09-08	77-05-30	77-05-31	77-06-01	77-06-02
02237116	29	Camp Creek at Eron Road near Atlanta	-	1	-	-	-	1	-	-	-	-	4	-	-	-
02237160	30	Deep Creek at SR 70 near Tell	-	1	-	-	-	1	-	-	-	-	-	1	-	-
02237170	31	Chattahoochee River at SR 92 near Fairburn	-	8	-	-	4	2	-	-	8	-	2	14	16	6
02237200	32	Anneewakee Creek at SR 166 near Douglasville	-	1	-	-	-	1	-	-	-	-	3	1	-	-
02237250	36	Bear Creek at SR 166 near Douglasville	-	1	-	-	-	1	-	-	-	-	4	-	-	-
02237260	38	Chattahoochee River (above Bear Creek) near Rico	-	-	-	-	-	1	-	-	-	-	-	-	12	7
02237320	39	Bear Creek at SR 70 near Rico	-	1	-	-	-	1	-	-	-	-	3	1	-	-
02237438	40	Dog River at SR 166 near Fairplay	-	1	-	-	-	2	-	-	-	-	3	1	-	-
02237445	41	Chattahoochee River (Capps Ferry Bridge) near Rico	-	-	-	-	1	1	-	-	5	1	2	14	15	7
02237454	42	Wolf Creek at SR 5 near Banning	-	1	-	-	-	1	-	-	-	-	4	-	-	-
02237457	43	Chattahoochee River at Hutcheson's Ferry near Rico	-	-	-	-	-	-	-	-	2	-	-	-	13	6
02337500	44	Snake Creek near Whitesburg	-	1	-	-	-	1	-	-	-	-	4	-	-	-
02237980	45	Cedar Creek at SR 70 near Roscoe	-	1	-	-	-	1	-	-	-	-	3	-	-	-
02238000	46	Chattahoochee River (U.S. Alt.) near Whitesburg	-	3	-	-	-	4	-	-	5	1	2	16	17	12

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TABLE 4-12. PARAMETERS MEASURED DURING INTENSIVE USGS RIVER SURVEYS.

Survey Dates	Parameters Measured During Survey*
11 July 1976 to 12 July 1976	temperature, discharge flow, conductance, DO, BOD_5, pH, total-N, Organic-N, NH_3-N, NO_2-N, Total-P, fecal coliform, fecal strep., Ortho-P.
28 August 1976 to 31 August 1976	As, Cr, Cu, Pb, Zn, fecal coliform, fecal strep., suspended solids, Ortho-P, suspended sediment, temperature, discharge flow, conductance, DO, BOD_5, COD, pH, solid residue, non-filterable solid residue, Total-N, Organic-N, NH_3-N, NO_2-N, Total-P, TOC.
5 September 1976 to 8 September 1976	temperature, discharge flow, DO, BOD_5, Total-N.
30 May 1977 to 3 June 1977	temperature, discharge flow, conductance, DO, BOD_5, CBODu, Total-N, Organic-N, NH_3-N, NO_2-N, Total-P, TOC, Ortho-P.

* Some samples were not analyzed for all parameters.

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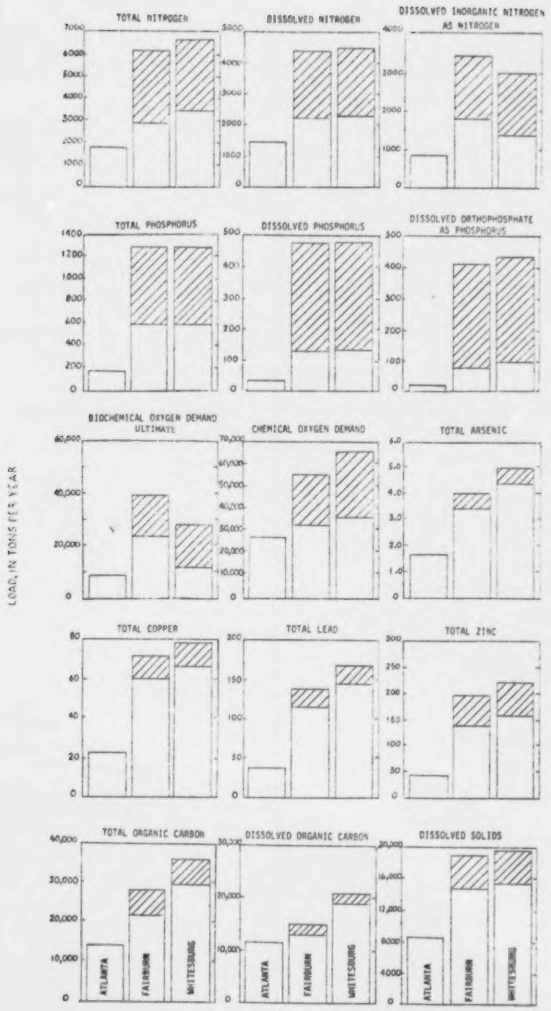

Figure 4-6a. Comparison of total point and non-point loads at three stations in the Chattahoochee River (after Stamer et al., 1978). The shaded areas represent point loads, and the unshaded areas represent non-point loads.

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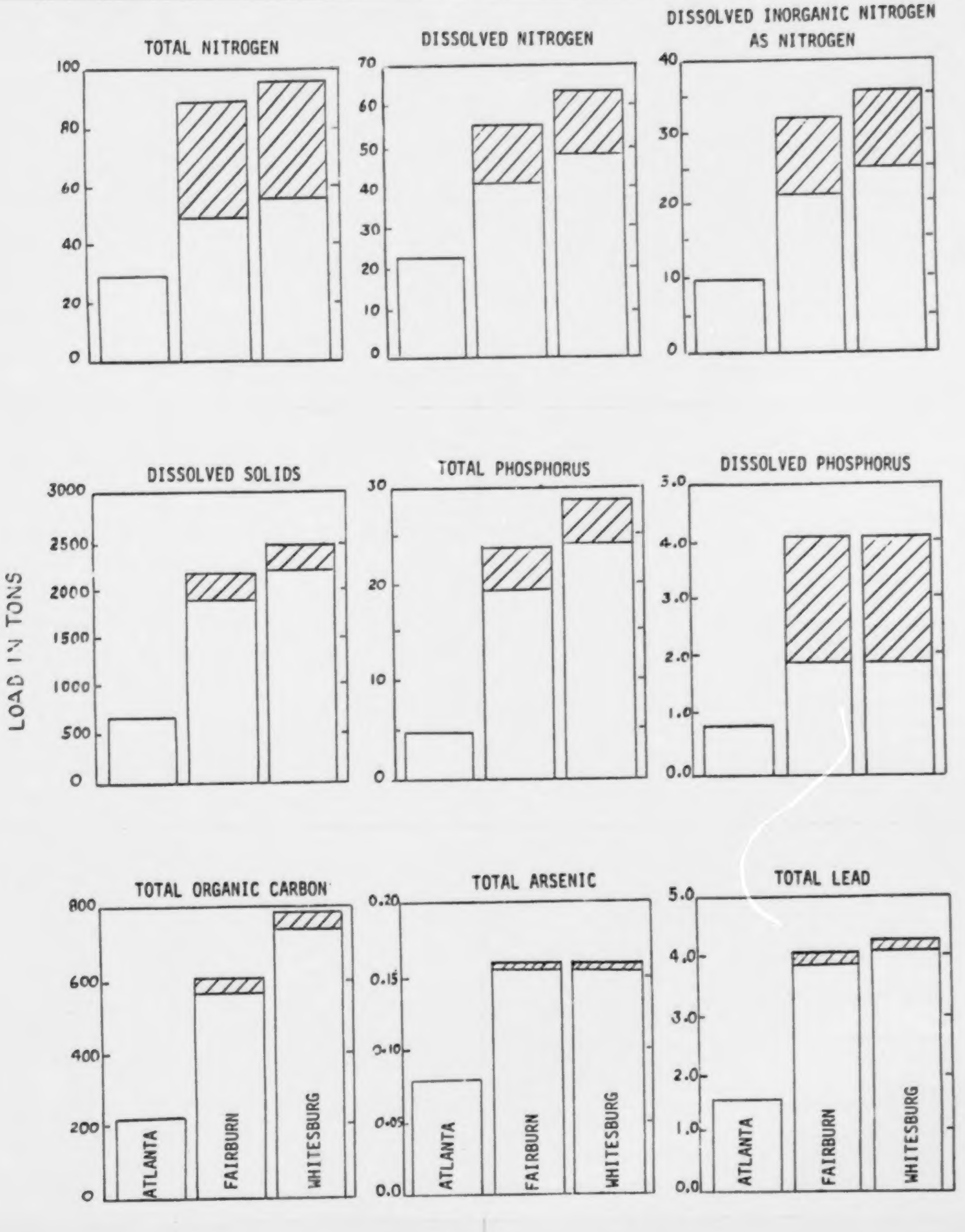

Figure 4-6b. Comparison of total point and non-point loads at three stations in the Chattahoochee River (after Stamer et al., 1978). The shaded areas represent point loads, and the unshaded areas represent non-point loads.

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Atlanta gage to the Whitesburg gage under low flow conditions. The positions of the USGS sampling stations are given in Table 4-1 and Figure 4-1. The dates of the intensive surveys and the numbers of water samples taken on each date are given in Table 4-11, and the water quality parameters analyzed in the water samples are shown in Table 4-12. The water quality data measured during the intensive surveys are included in the computer data set.

Reaeration--

McCutcheon (1982) presents reaeration coefficients for 14 reaches between Atlanta and Whitesburg derived from a study by Tsivoglu and Wallace (1972). These data are presented in Table 4-13. McCutcheon states that the values of reaeration coefficient appear to be insensitive to flow rate.

Biochemical Rate Constants--

McCutcheon (1982) used a variety of biochemical coefficients to calibrate the QUAL-II model for the Chattahoochee River. The values of the coefficients were held constant for all river reaches in the study area and for all four intensive surveys. The coefficients are given in Table 4-14.

McCutcheon found that the peak flows from the hydropower releases tend to scour the river bed. This scouring removes attached plants and leaves a sandy and rocky bed. As a result the river bed does not act as a significant source of nutrients. The peak hydropower releases also tend to flush the phytoplankton out of the study reach. This flushing dilution and the high turbidity of the river flows restrict phytoplankton growth in the river, and photosynthesis does not have a significant effect on this river section.

4-4-3 Measurement Listing

The river's channel cross sections and bed elevations are shown in Table 4-6 and Figure 4-3, and channel roughness coefficients are given in Table 4-7. Table 4-9 shows the results of a time of travel study, and Table 4-10 gives the loading rate parameters, average daily values of which were measured or estimated for the river's headwaters and other point sources. The actual values of these parameters for each of the four intensive surveys are given in the computer data set. Similarly, Table 4-11 shows the number of samples taken at each station during the surveys, and Table 4-12 shows the parameters that were measured in those samples. Again, the actual data values are included in the computer data set.

4-4-4 Sampling Techniques

Water Quality--

Stamer et al. (1978, p 21) give a brief description of the USGS water quality sampling techniques. Water samples were collected from streams at points where the streams were laterally well-mixed (McCutcheon, 1982, p 112), and the samples were depth integrated (Stamer et al., 1978, p 21). Temperature, specific conductance, pH, and DO were measured in situ (McCutcheon, 1982, p 72), while the other water quality parameters were measured in laboratory analyses using the methods described by Skougstad (1978).

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TABLE 4-13. REAERATION COEFFICIENTS FOR THE CHATTAHOOCHEE RIVER, ATLANTA TO WHITESBURG* (after McCutcheon, 1982).

Reach (River Miles)	Reaeration Coefficient (day^{-1}, base e, 25°C.)
302.97 - 300.50	1.75
300.50 - 299.00	0.54
299.00 - 294.00	1.21
298.77 - 292.80	1.46
292.80 - 288.54	1.03
288.54 - 286.18	1.03
286.18 - 281.91	0.84
281.91 - 280.21	0.47
281.50 - 277.50	0.29
277.50 - 276.00	0.57
276.00 - 271.25	0.98
271.25 - 267.25	2.66
267.25 - 262.25	2.77
262.25 - 259.75	1.17

* Coefficients for the middle reaches were derived from tracer measurements by Tsivoglou and Wallace (1972, p. 149); coefficients for the upstream and downstream reaches follow from calculations using the equation developed by Tsivoglou and Wallace (1972, p. 248) from Chattahoochee River data.

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TABLE 4-14. BIOCHEMICAL COEFFICIENTS FOR THE CHATTAHOOCHEE RIVER (adapted from QUAL-II modelling study by McCutcheon, 1982).

Coefficient	Value
Oxygen uptake per unit of ammonia oxidation	3.43 mg O/mg N
Oxygen uptake per unit of nitrite oxidation	1.14 mg O/mg N
Oxygen uptake per unit algae growth	1.6 mg O/mg Algae
Oxygen uptake per unit of algae respiration	2.0 mg O/mg Algae
Nitrogen content of algae	0.08 mg N/mg Algae
Phosphorus content of algae	0.012 mg P/mg Algae
Maximum specific algae growth rate	1.0 day^{-1}
Algae respiration rate	0.2 day^{-1}
Nitrogen half saturation constant	0.03 mg/l
Phosphorus half saturation constant	0.04 mg/l
Light half saturation constant	0.03 Langleys/min
BOD decay rate coefficient	0.16 day^{-1}
Chlorophyll a to algae ratio	75 μg Chl a/mg Algae
Ammonia oxidation rate coefficient	0.30 day^{-1}
Nitrite oxidation rate coefficient	2.6 day^{-1}
Benthos ammonia source rate (per ft stream length)	0.0 mg/ft-day
Benthos phosphorus source rate (per ft stream length)	0.0 mg/ft-day
Benthos BOD source rate (per ft stream length)	0.0 mg/ft-day
Coliform decay rate coefficient	0.08 day^{-1}

Loading Rates--

Loading rates were derived for the seven WTF's and the river's tributaries. The loading rates were calculated by multiplying the nutrient concentrations, measured as described above, by the measured or estimated flow rates. The flow rates of some tributaries were measured, while others were estimated, and the flow rates of the WTF's were derived from monthly operator records. Where the loads were estimated, the estimates were revised if necessary by using in-stream measurements of discharge and water quality. Using this method it was possible to revise the waste load by considering a mass balance for that section of the river (McCutcheon, 1982, p 21).

Reaeration--

Reaeration in the middle reaches of the river was derived from tracer measurements by Tsivoglou and Wallace (1972, p 149). Reaeration coefficients for the upstream and downstream sections of the river were derived from calculations presented by the same authors.

Biochemical Rate Coefficients--

The biochemical rate constants were derived by calibration and verification of the QUAL-II model by McCutcheon (1982). The estimate of BOD decay rate was also based on previous modelling studies and on analysis of BOD samples (McCutcheon, 1982, p 110). The fecal coliform die-off rate was based on information from the EPA report by Zison et al. (1978) because the in-stream measurements were inadequate for estimating this parameter. Orthophosphate and nitrate uptake rates were set to zero because biomass growth and nutrient cycling appear to be negligible (because of high water turbidity and flushing by high releases from hydropower dams). Biochemical interactions with the river sediment were also assumed to be negligible. This seems reasonable because peak hydropower releases scour the river bottom, leaving only sand and bedrock in most places.

4-5 COMPUTER DATA SET

The computer data set contains two distinct data collections. One is a QUAL-II model input data deck which contains hydraulic data described in Tables 4-4, 4-5, and 4-7; source loading data described in Table 4-10; and biochemical reaction coefficients described in Table 4-14. The second data collection is a series of four water quality surveys by the USGS from which the QUAL-II modelling data were derived. The USGS data collection is described in Tables 4-11 and 4-12, and the positions of the measuring stations are given in Table 4-1 and Figure 4-1.

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SECTION 5

LOWER FOX RIVER

5-1. INTRODUCTION

The lower Fox River is 64 km (40 mi) long, and runs in a generally northeast direction from Lake Winnebago to Green Bay in Wisconsin (Figure 5-1). The river drops by 51.3 m (168 ft) from Lake Winnebago to Green Bay, and is regulated and rendered navigable by 17 locks. The Fox River drainage basin has an area of 16,687 km^2 (6443 mi^2), but only 4% of this area drains directly into the lower Fox River. The remaining 96% of the drainage basin drains into the river by way of its headwaters in Lake Winnebago.

The Lower Fox River receives effluent from 33 point sources and has been extensively studied by the Wisconsin Department of Natural Resources for a wasteload allocation study. The Wisconsin DNR developed a version of the QUAL-II model with an extended algal dynamics routine, which they called QUAL-III. This model was calibrated for steady state conditions using eleven separate water quality surveys of the Lower Fox River. The surveys were performed between June 1972 and July 1977, mostly under low flow conditions.

5-2. SOURCE LITERATURE

The Lower Fox River has been studied extensively, and background information on the condition of the river may be drawn from the report on automatic quality sampling from 1972 to 1981 (Weckwerth and Fenske,1982). Patterson et al. (1975) present a more intensive study of the Lower Fox River and its effect on Lower Green Bay during 1973 and 1974.

The data presented in the report were drawn from a series of intensive river surveys presented by the Wisconsin Department of Natural Resources (1977) which were used in a river quality modelling effort for wasteload allocation (Patterson, 1980). The river quality modelling was performed using the QUAL-III model, an adaptation of QUAL-II with a modified algal dynamics routine. A description of the QUAL-III model and its input formats are contained in a report by the Wisconsin Department of Natural Resources (1979). Since the input is very easy to understand and also contains much useful information on wasteloads, rate coefficients, and meteorology, it is included as part of the computer data set.

5-3. RIVER BASIN DESCRIPTION

5-3-1 Study Area

The Lower Fox River is 64 km (40 mi) long, and runs from Lake Winnebago to Green Bay. The river drops by 51.3 m (168.3 ft) over its length, and

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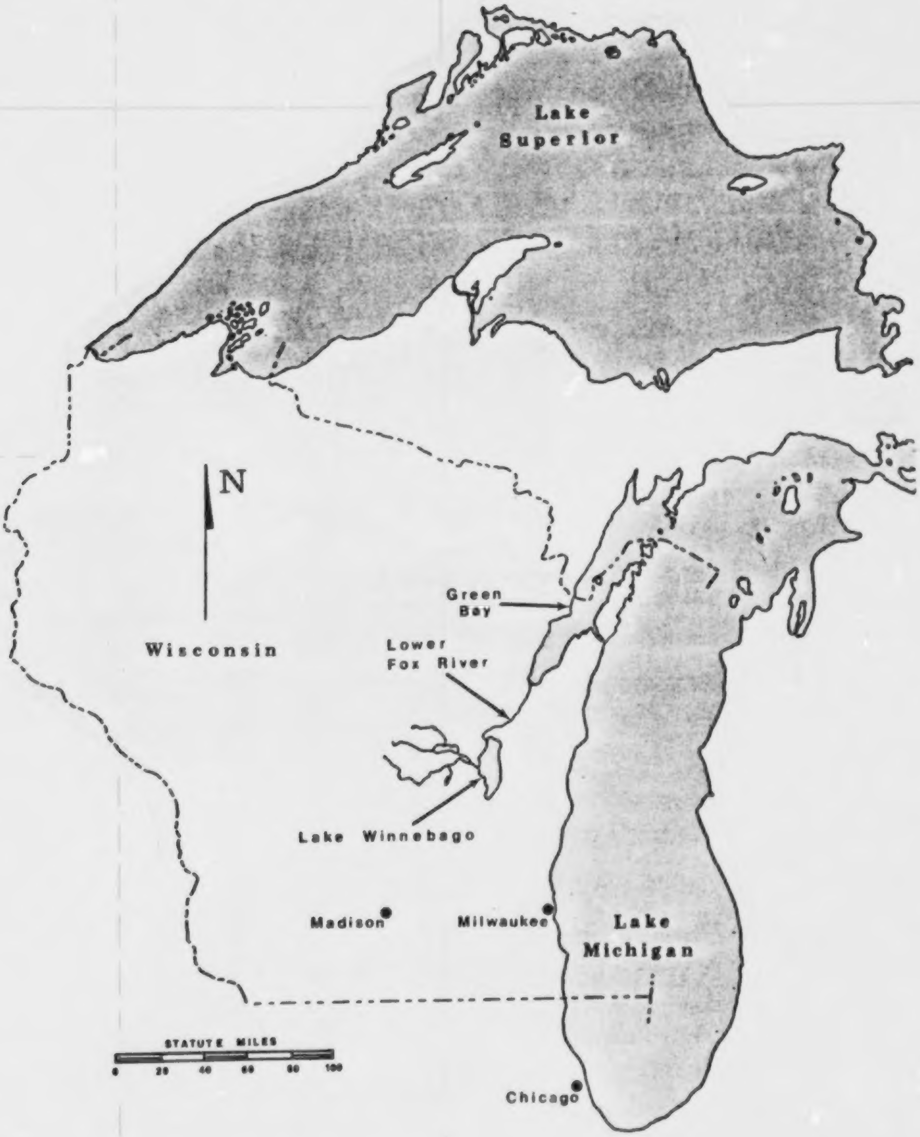
Lake Superior
N
Wisconsin
Green Bay
Lower Fox River
Lake Winnebago
Madison
Milwaukee
Lake Michigan
STATUTE MILES
0 20 40 60 80 100
Chicago

Figure 5-1. Location map showing the Lower Fox River.

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contains 17 locks (plus 2 guard locks), 33 effluent sources (13 of which are STP's), 15 withdrawal points, and 13 dams. The Wisconsin DNR modelled the river using 49 reaches.

The general location of the river is shown in Figure 5-1, and the locations of the reach boundaries and hydraulic structures are shown in the detail maps in Figure 5-2 (a to i).

5-3-2 Hydrologic Data

Point Inflows--

The river has five tributaries and receives effluent from 13 STP's and twenty other sources. There are also 15 points at which water is withdrawn. The positions of these point sources and withdrawals are listed in Table 5-1 and shown in Figure 5-2.

The flow rates and water temperatures of the headwaters, tributaries, point sources, and withdrawal points are given in the computer data set in QUAL-III input format. The 7Q10 flow for the Lower Fox River is 26.9 m^3/s (950 cfs).

Non-Point Inflows--

The non-point inflows cannot be back calculated by referring to river flows and point inflows because the river flow is only measured at one point. It is reasonable to ignore the non-point inflows since 96% of the Fox River drainage basin drains into the Lower Fox River via its Lake Winnebago headwaters. The runoff from the remaining 4% of the drainage basin, which enters the Lower Fox River directly, can mostly be accounted for by the tributary flows.

5-3-3 Hydraulic Data

River Cross Sections--

For modelling purposes, the Wisconsin DNR divided the Lower Fox River into 49 reaches. These reaches are shown in Figure 5-2, and their boundary positions, mean depths, and mean cross sectional areas area given in Table 5-2.

Actual cross sectional profiles were not available at the time of writing. Approximate profiles can be derived from the National Ocean Survey bathymetric chart "Chart No. 14916 - Lake Winnebago and Lower Fox River", but accuracy is limited by the comparatively wide spacing of the depth soundings. The chart contains other useful information, and is available from: Distribution Division C-44, National Ocean Survey, Riverdale, MD 20737, (Telephone 301-436-6990).

Stream Slope--

The streambed profile, showing locks and bed elevations, is given in Figure 5-3.

Average Flow Velocities--

The Wisconsin DNR did not measure flow velocities directly or do time of travel studies on the Lower Fox River. However the flow velocities can be

TABLE 5-1. LOCATIONS OF MAJOR WASTELOADS, WATER WITHDRAWALS, TRIBUTARIES, MUNICIPAL BYPASSES AND HYDRAULIC STRUCTURES IN THE LOWER FOX RIVER (after Wisconsin DNR, 1977).

Wasteload Number	Name	Type	River Mile	River Kilometer
1	John Strange Paper Co.	Withdrawal	38.9	62.6
2	John Strange Paper Co.	Effluent	38.8	62.4
3	George Whiting	Withdrawal	38.3	61.6
4	George Whiting	Effluent	38.2	61.5
5	Neenah-Menasha Sewage Treatment Plant (STP)	Effluent	38.1	61.3
6	Neenah Bypass #1	Municipal Bypass	39.3	63.2
7	Kimberly-Clark and Bergstrom Paper Mills	Withdrawal	38.8	62.4
8	Kimberly-Clark Neenah and Badger-Globe Mills	Effluent	38.5	62.0
9	Bergstrom Paper Company	Effluent	38.3	61.6
10	Neenah Bypass #2	Municipal Bypass	38.2	61.5
11	Neenah Bypasses 3 and 4	Municipal Bypass	38.1	61.3
12	Kimberly-Clark Lakeview Mill	Withdrawal	38.0	61.2
13	Kimberly-Clark Lakeview Mill	Effluent	37.9	61.0
14	Wisconsin Tissue Mills	Withdrawal	37.0	59.5
15	Wisconsin Tissue Mills	Effluent	36.8	59.2
16	Town of Menasha East STP	Effluent	35.8	57.6
17	Town of Menasha West STP	Effluent	35.7	57.5
18	Town of Menasha Bypasses 1-4	Municipal Bypass	35.6	57.3
19	Butte des Morts Utility District STP	Effluent	34.7	55.8
20	Mud Creek	Tributary	34.6	55.7
21	Appleton Bypass #4	Municipal Bypass	32.8	52.8
22	Upper Appleton Dam	Dam	32.4	52.1
23	Appleton Bypasses 3 and 5	Municipal Bypass	32.3	52.0
24	Riverside Paper Corporation	Withdrawal	32.1	51.7
25	Appleton Bypass #6	Municipal Bypass	32.0	51.5
26	Appleton Bypasses #2 and #7	Municipal Bypass	31.8	51.2
27	Riverside Paper Corporation	Effluent	31.4	50.5
28	Lower Appleton Dam	Dam	31.1	50.1
29	Foremost Foods, Appleton	Effluent	31.0	49.9
30	Consolidated Papers, Appleton	Withdrawal	30.9	49.7
31	Consolidated Papers, Appleton	Effluent	30.7	49.4
32	Appleton Bypass #8	Municipal Bypass	30.5	49.1
33	Appleton Bypass #1 and #9	Municipal Bypass	29.9	48.1
34	Appleton STP	Effluent	29.8	48.0
35	Kimberly Bypasses 1-6	Municipal Bypass	28.1	45.2
36	Mid Tech Paper Co., Kimberly	Effluent	27.8	44.7
37	Mid Tech Paper Co., Kimberly	Withdrawal	27.6	44.4
38	Cedars Dam	Dam	27.5	44.3
39	Kimberly Bypasses 7-18	Municipal Bypass	27.3	43.9
40	Little Chute Bypasses 1 and 2	Municipal Bypass	27.1	43.6
41	Kimberly STP	Effluent	27.0	43.5
42	Combined Locks Bypass 2	Municipal Bypass	26.9	43.3
43	Upper Little Chute Dam	Dam	26.8	43.1
44	Little Chute STP	Effluent	26.7	43.0
45	Combined Locks Bypass 3	Municipal Bypass	26.6	42.8
46	Appleton Papers, Combined Locks Mill	Withdrawal	26.0	41.8
47	Appleton Papers, Combined Locks Mill (Before 1972)	Effluent	25.8	41.5

(continued)

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Table 5-1 (concluded)

Wasteload Number	Name	Type	River Mile	River Kilometer
48	Combined Locks Bypasses 1 and 4	Municipal Bypass	25.7	41.4
49	Appleton Papers, Combined Locks Mill (1973 On)	Effluent	25.6	41.2
50	Little Chute Bypasses 3 and 4	Municipal Bypass	25.4	40.9
51	Kaukauna Bypass 7	Municipal Bypass	25.2	40.6
52	Kaukauna Bypass 3	Municipal Bypass	24.4	39.3
53	Upper Kaukauna Dam	Dam	23.9	38.5
54	Kaukauna Bypasses 2 and 4	Municipal Bypass	23.8	38.3
55	Thilmany Pulp and Paper Company	Withdrawal	23.0	37.0
56	Kaukauna or Heart of the Valley STP	Effluent	22.5	36.2
57	Thilmany Pulp and Paper Company	Effluent	22.4	36.0
58	Kaukauna Bypasses 1, 5 and 6	Municipal Bypass	22.3	35.9
59	Rapide Croche Dam	Dam	19.2	30.9
60	Wrightstown Bypass 1	Municipal Bypass	17.9	28.8
61	Plum Creek	Tributary	17.5	28.2
62	Wrightstown Bypass 2	Municipal Bypass	17.2	27.7
63	Wrightstown STP	Effluent	17.1	27.5
64	Apple Creek	Tributary	15.1	24.3
65	Little Rapids Dam	Dam	13.1	21.1
66	Hickory Grove Sanitarium STP	Effluent	12.3	19.8
67	DePere Dam	Dam	7.4	11.9
68	Nicolet Paper Company	Withdrawal	7.3	11.7
69	Nicolet Paper Company	Effluent	7.2	11.6
70	DePere Bypasses 1-3	Municipal Bypass	6.4	10.3
71	Old DePere STP	Effluent	6.3	10.1
72	New DePere STP	Effluent	6.2	10.0
73	Ashwaubenon Creek	Tributary	5.7	9.2
74	Fort Howard Paper Co.	Withdrawal	4.1	6.6
75	Fort Howard Paper Co.	Effluent	3.9	6.3
76	Green Bay Bypass 2	Municipal Bypass	2.8	4.5
77	Green Bay Bypass 1 and 4	Municipal Bypass	2.2	3.5
78	Green Bay Bypass 3	Municipal Bypass	1.4	2.3
79	East River	Tributary	1.3	2.1
80	American Can Co.	Withdrawal	1.2	1.9
81	American Can Co., Water Intake Treatment	Effluent	1.1	1.8
82	Proctor and Gamble Paper Products Co.	Withdrawal	1.0	1.6
83	Green Bay Packaging, Inc.	Withdrawal	0.9	1.4
84	Proctor and Gamble Paper Products Co.	Effluent	0.8	1.3
85	American Can Co. Prediversion	Effluent	0.7	1.1
86	Green Bay Packaging	Effluent	0.6	1.0
87	American Can Co. Lagoon	Effluent	0.4	0.6
88	Old Green Bay STP	Effluent	0.2	0.3

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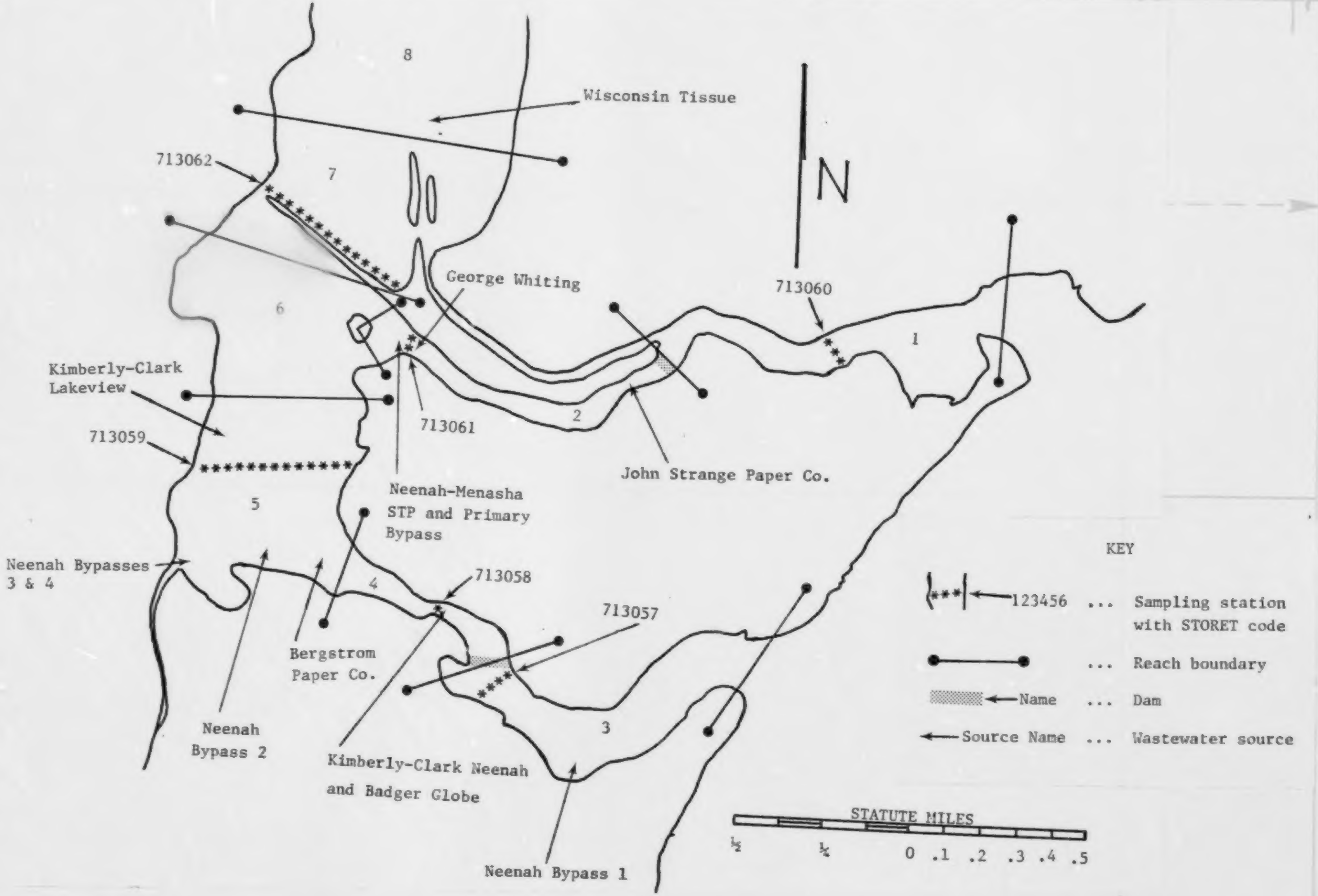
8
Wisconsin Tissue
N
713062
7
George Whiting
713060
1
6
Kimberly-Clark Lakeview
713061
2
713059
John Strange Paper Co.
Neenah-Menasha STP and Primary Bypass
5
KEY
Neenah Bypasses 3 & 4
713058
4
713057
123456 ... Sampling station with STORET code
... Reach boundary
Name ... Dam
Source Name ... Wastewater source
Bergstrom Paper Co.
3
Neenah Bypass 2
Kimberly-Clark Neenah and Badger Globe
STATUTE MILES
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0 .1 .2 .3 .4 .5
Neenah Bypass 1

Figure 5-2a. Detail map showing segments of the Lower Fox River (after Wisconsin DNR, 1977).

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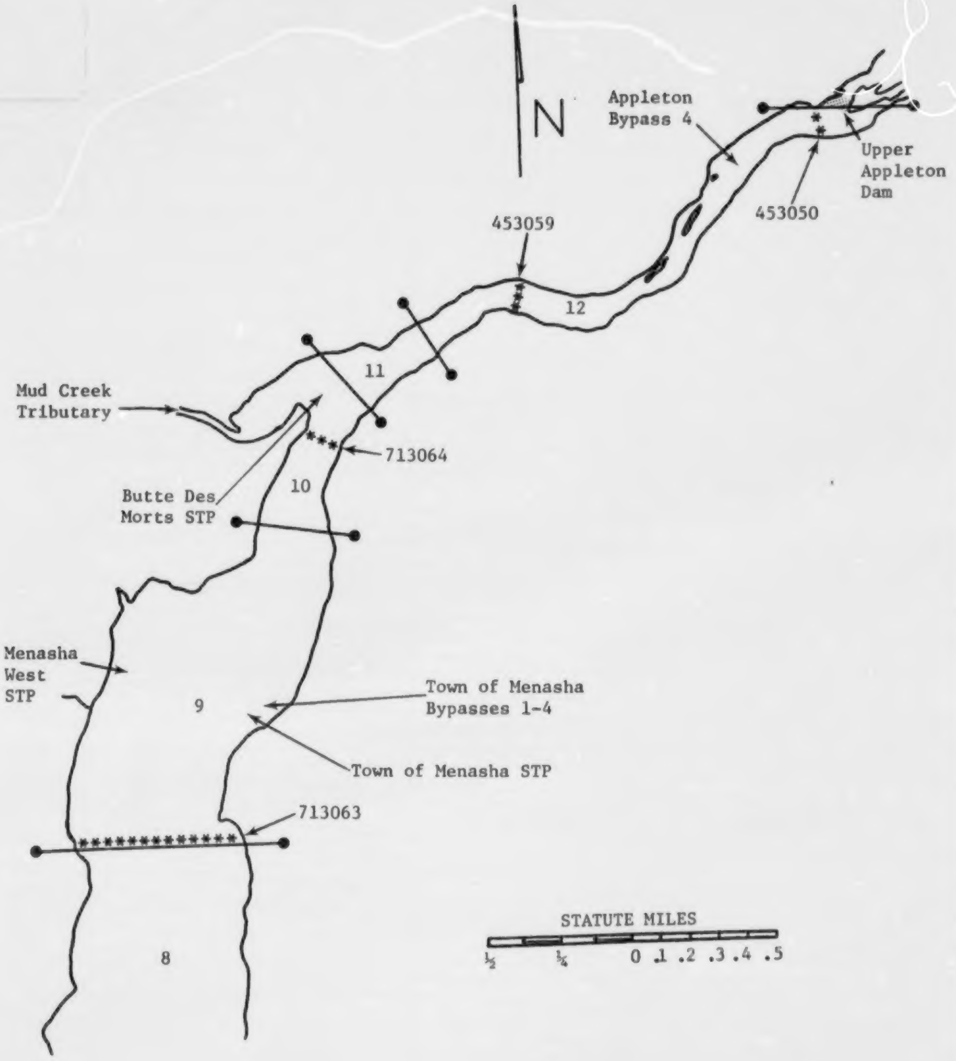

N
Appleton Bypass 4
Upper Appleton Dam
453050
453059
12
11
Mud Creek Tributary
713064
10
Butte Des Morts STP
Menasha West STP
9
Town of Menasha Bypasses 1-4
Town of Menasha STP
713063
8
STATUTE MILES
½
¼
0 .1 .2 .3 .4 .5

Figure 5-2b. Detail map showing segments of the Lower Fox River (after Wisconsin DNR, 1977).

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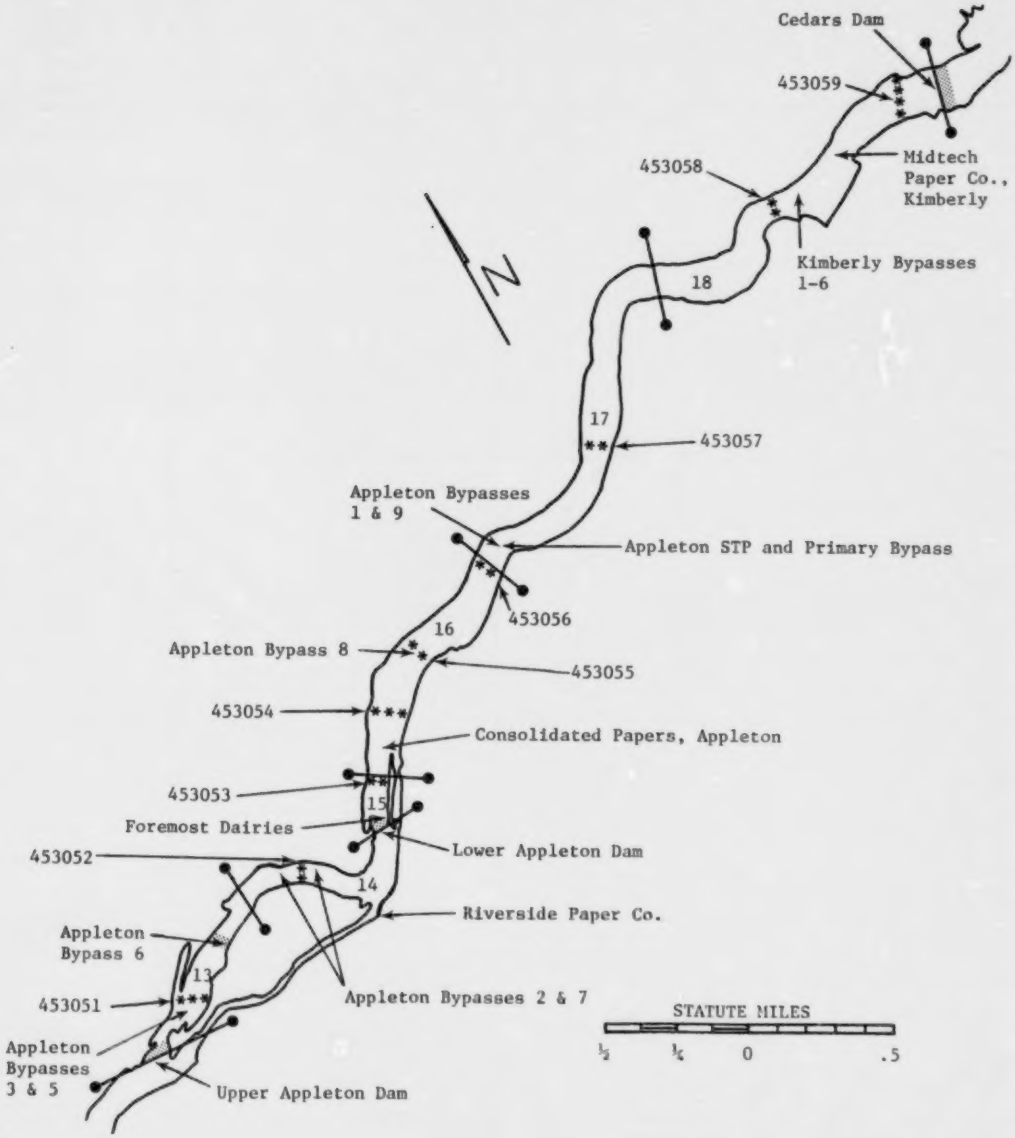
Cedars Dam
453059
Midtech Paper Co., Kimberly
453058
Kimberly Bypasses 1-6
N
18
17
453057
Appleton Bypasses 1 & 9
Appleton STP and Primary Bypass
453056
16
Appleton Bypass 8
453055
453054
Consolidated Papers, Appleton
453053
15
Foremost Dairies
Lower Appleton Dam
453052
14
Riverside Paper Co.
Appleton Bypass 6
13
453051
Appleton Bypasses 2 & 7
STATUTE MILES
½
¼
0
.5
Appleton Bypasses 3 & 5
Upper Appleton Dam

Figure 5-2c. Detail map showing segments of the Lower Fox River (after Wisconsin DNR, 1977).

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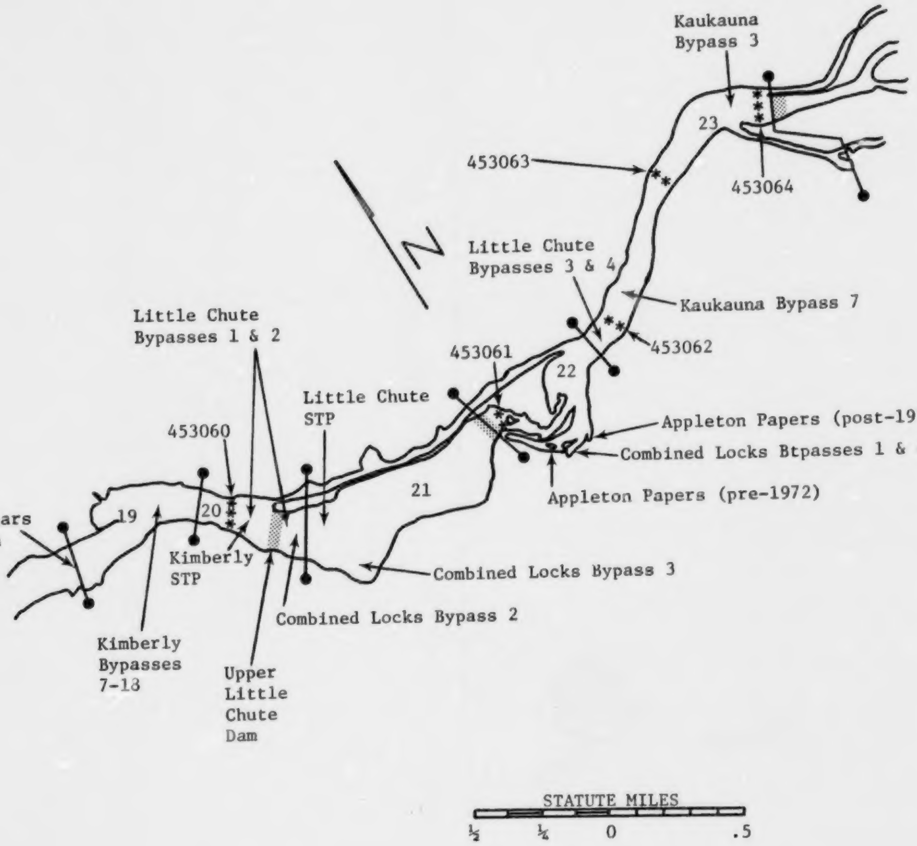
Kaukauna Bypass 3
23
453063
453064
N
Little Chute Bypasses 3 & 4
Kaukauna Bypass 7
Little Chute Bypasses 1 & 2
453061
453062
22
Little Chute STP
453060
Appleton Papers (post-1972)
Combined Locks Btpasses 1 & 4
Appleton Papers (pre-1972)
21
Cedars Dam
19
20
Kimberly STP
Combined Locks Bypass 3
Combined Locks Bypass 2
Kimberly Bypasses 7-13
Upper Little Chute Dam
STATUTE MILES
½
¼
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.5

Figure 5-2d. Detail map showing segments of the Lower Fox River (after Wisconsin DNR, 1977).

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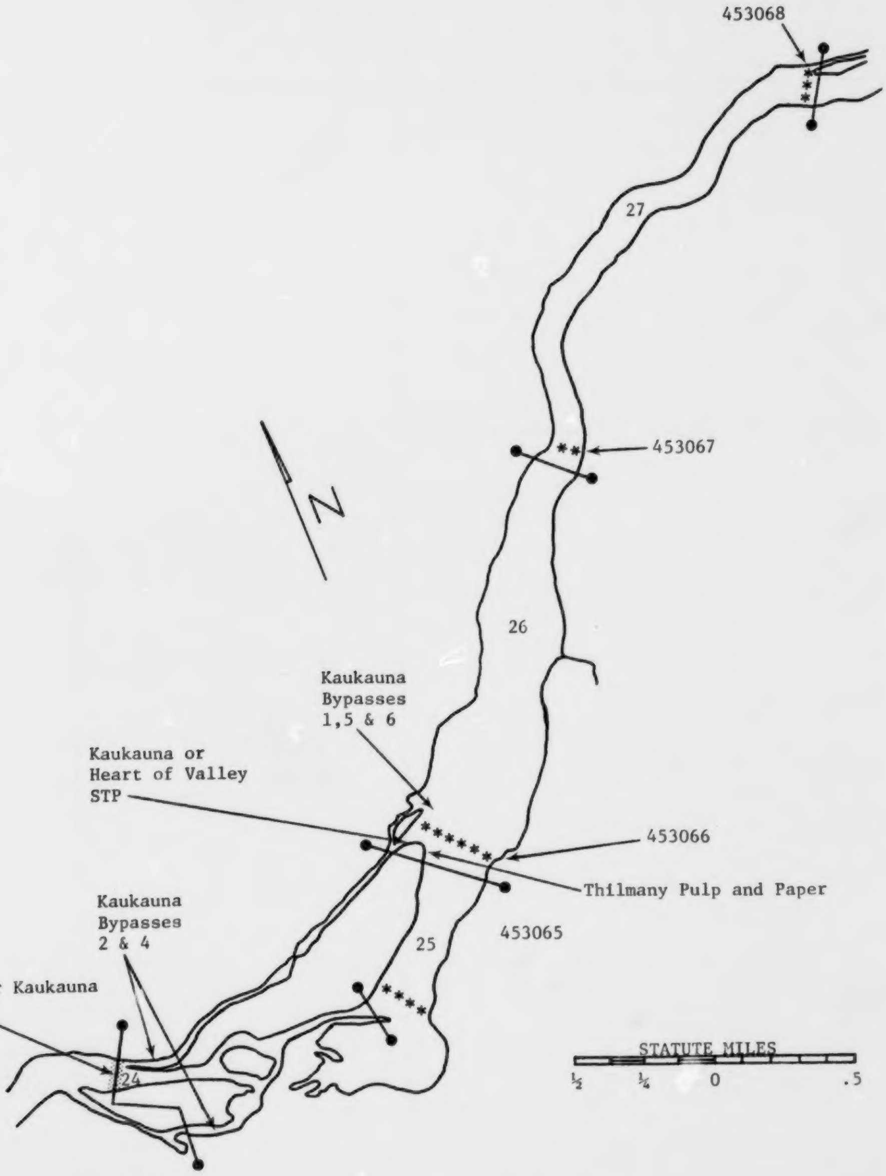
453068
27
453067
N
26
Kaukauna Bypasses 1,5 & 6
Kaukauna or Heart of Valley STP
453066
Thilmany Pulp and Paper
453065
25
Kaukauna Bypasses 2 & 4
Upper Kaukauna Dam
24
STATUTE MILES
½
¼
0
.5

Figure 5-2e. Detail map showing segments of the Lower Fox River (after Wisconsin DNR, 1977).

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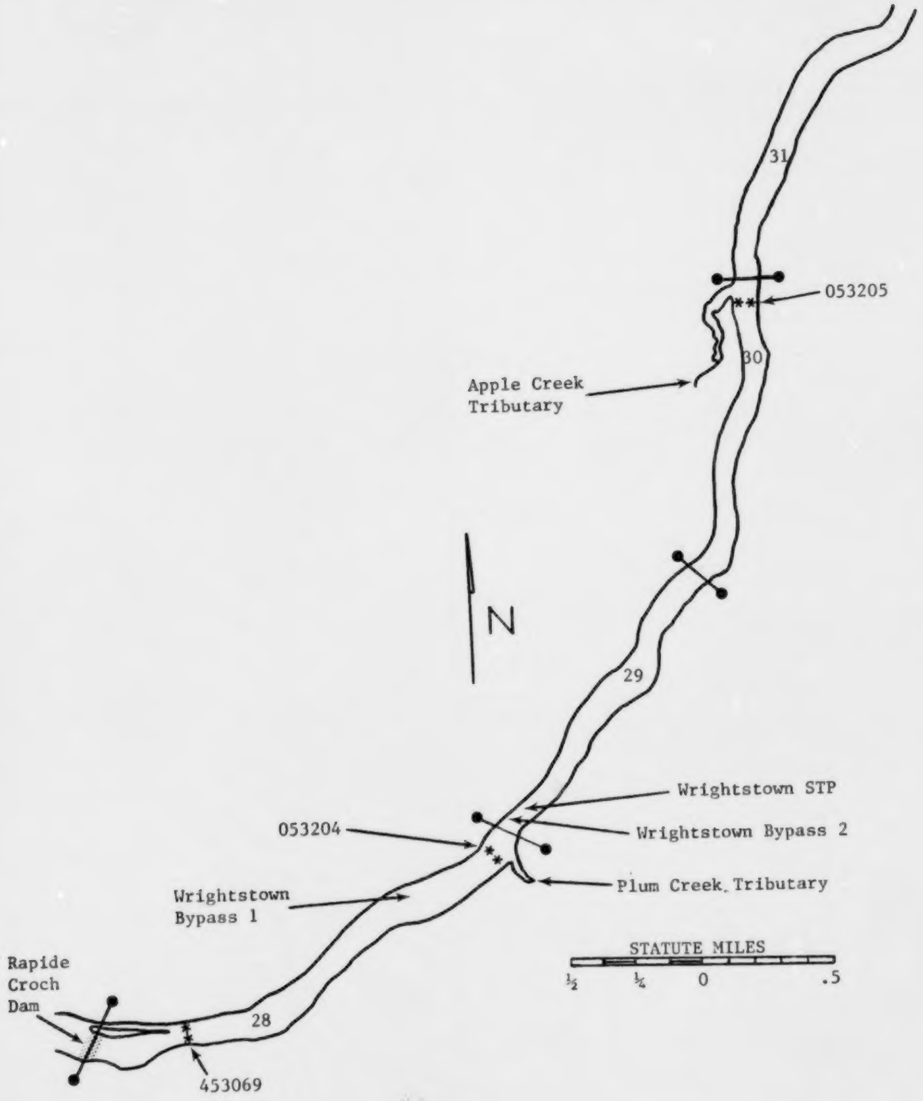
31
053205
Apple Creek Tributary
30
N
29
Wrightstown STP
053204
Wrightstown Bypass 2
Plum Creek Tributary
Wrightstown Bypass 1
STATUTE MILES
½
¼
0
.5
Rapide Croch Dam
28
453069

Figure 5-2f. Detail map showing segments of the Lower Fox River (after Wisconsin DNR, 1977).

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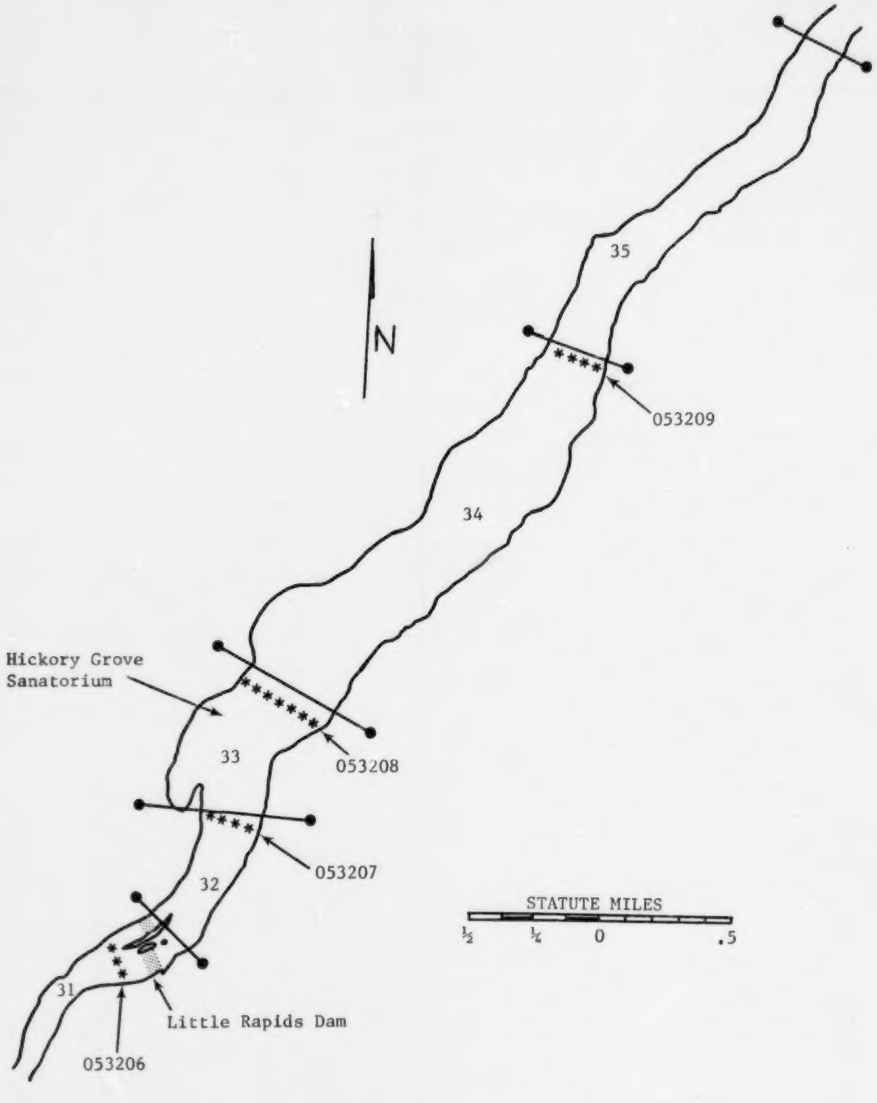
35
N
053209
34
Hickory Grove
Sanatorium
33
053208
053207
32
STATUTE MILES
½
¼
0
.5
31
Little Rapids Dam
053206

Figure 5-2g. Detail map showing segments of the Lower Fox River (after Wisconsin DNR, 1977).

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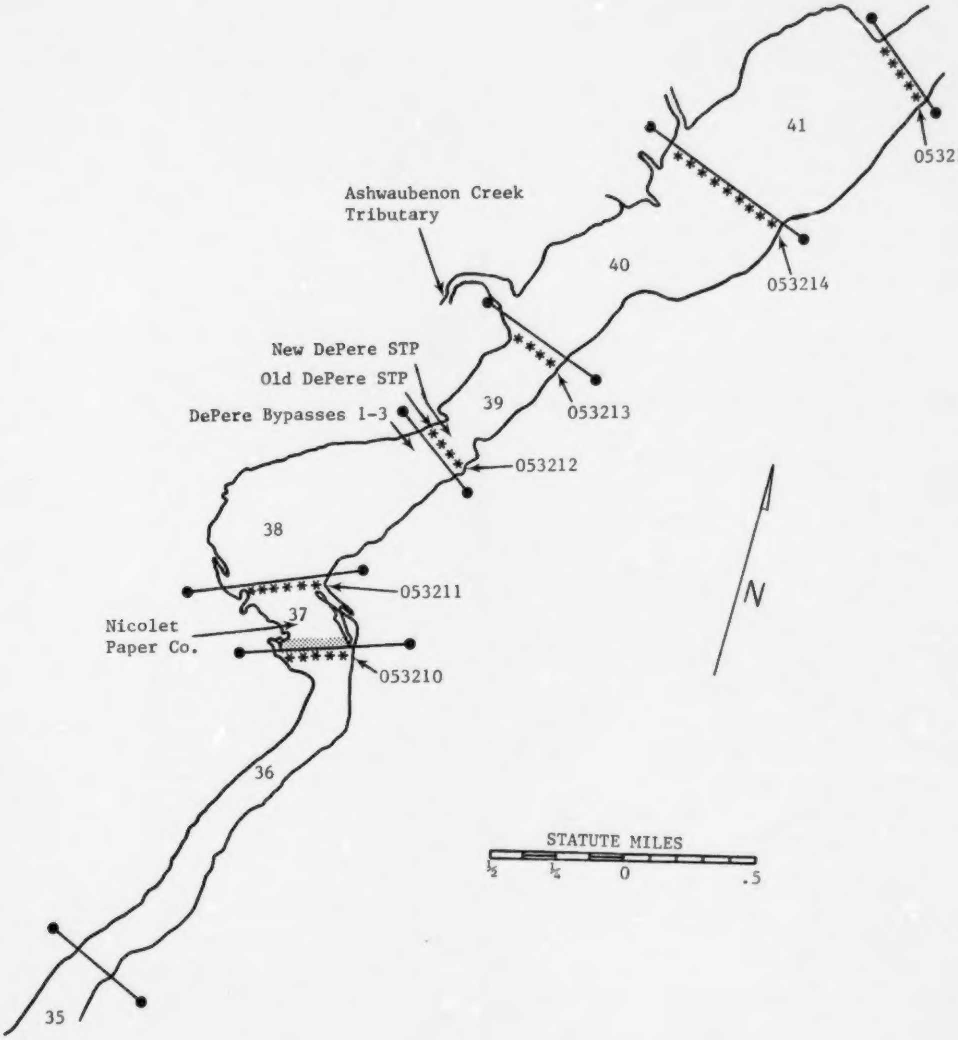
053215
41
Ashwaubenon Creek Tributary
40
053214
New DePere STP
Old DePere STP
DePere Bypasses 1-3
39
053213
053212
38
N
053211
37
Nicolet Paper Co.
053210
36
STATUTE MILES
½
¼
0
.5
35

Figure 5-2h. Detail map showing segments of the Lower Fox River (after Wisconsin DNR, 1977).

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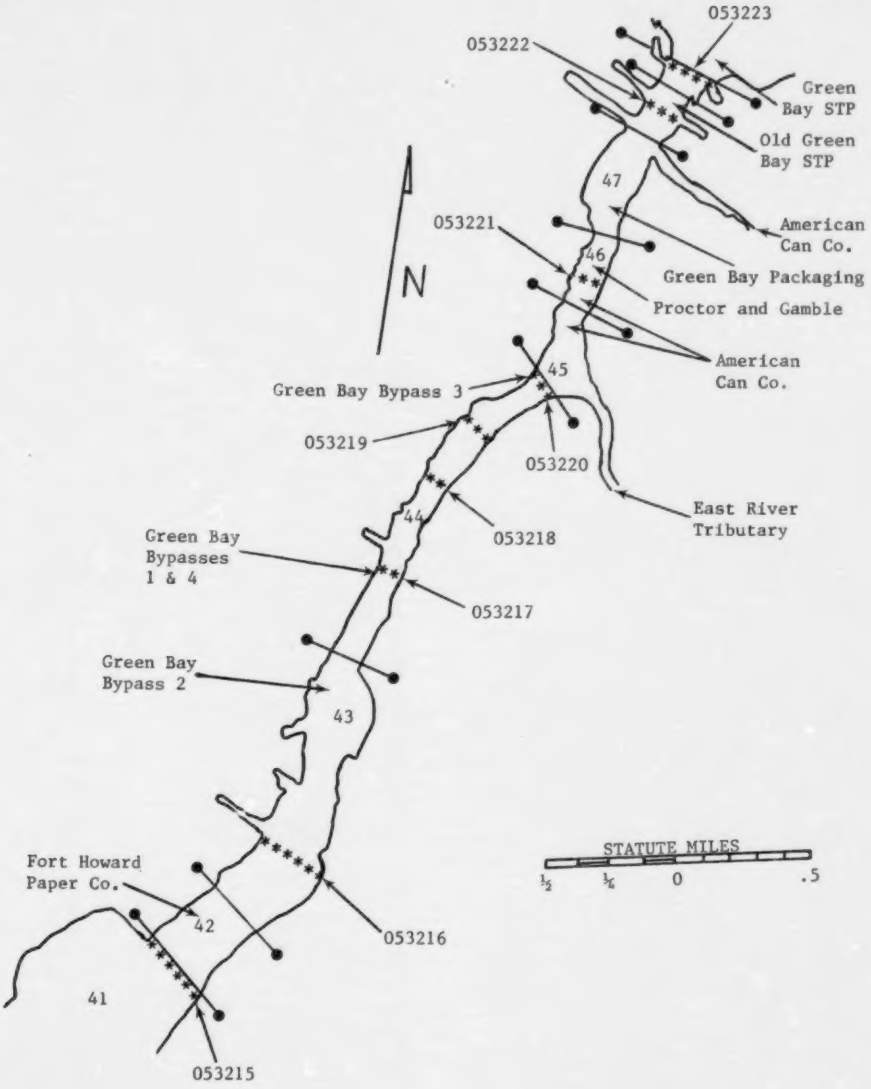
053223
053222
Green Bay STP
Old Green Bay STP
47
American Can Co.
053221
46
Green Bay Packaging
Proctor and Gamble
N
American Can Co.
45
Green Bay Bypass 3
053219
053220
East River Tributary
44
053218
Green Bay Bypasses 1 & 4
053217
Green Bay Bypass 2
43
STATUTE MILES
½
¼
0
.5
Fort Howard Paper Co.
42
053216
41
053215

Figure 5-2i. Detail map showing segments of the Lower Fox River (after Wisconsin DNR, 1977).

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TABLE 5-2. LOCATIONS, AVERAGE DEPTHS, AND CROSS SECTIONAL AREAS OF FOX RIVER SEGMENTS (after Wisconsin DNR, 1977).

Reach #	Starting Point (mile)	Starting Point (km)	Ending Point (mile)	Ending Point (km)	Average Depth (ft)	Average Depth (m)	Average Cross-Sectional Area (ft^2)	Average Cross-Sectional Area (m^2)
1	40.0	64.4	39.0	62.8	3.71	1.13	2,501	232.4
2	39.0	62.8	37.9	61.0	2.00	0.61	662	61.5
3	39.7	63.9	38.8	62.4	4.55	1.39	3,463	321.7
4	38.8	62.4	38.3	61.6	5.00	1.52	957	88.9
5	38.3	61.6	37.8	60.8	2.67	0.81	3,348	311.0
6	37.8	60.8	37.4	60.2	4.45	1.36	7,370	681.7
7	37.4	60.2	37.0	59.5	5.20	1.58	9 564	888.5
8	37.0	59.5	36.2	58.3	5.31	1.62	15,127	1,405.3
9	36.2	58.3	35.0	56.3	5.54	1.69	13,433	1,248.0
10	35.0	56.3	34.5	55.5	11.33	3.45	10,888	1,011.5
11	34.5	55.5	34.2	55.0	12.47	3.80	9,986	927.7
12	34.2	55.0	32.4	52.1	6.67	2.03	4,022	373.7
13	32.4	52.1	31.9	51.3	3.00	0.91	1,584	147.2
14	31.9	51.3	31.0	49.9	3.20	0.98	1,464	136.0
15	31.0	49.9	30.8	49.6	1.44	0.44	684	63.5
16	30.8	49.6	30.0	48.3	5.80	1.77	3,648	338.9
17	30.0	48.3	28.7	46.2	6.70	2.04	4,194	389.6
18	28.7	46.2	27.5	44.3	6.70	2.04	4,194	389.6
19	27.5	44.3	27.1	43.6	3.30	1.00	2,660	247.1
20	27.1	43.6	26.7	43.0	6.70	2.04	4,556	423.3
21	26.7	43.0	25.9	41.7	6.50	1.98	6,592	612.4
22	25.9	41.7	25.4	40.9	3.30	1.00	1,760	163.5
23	25.4	40.9	23.9	38.5	7.00	2.13	5,544	515.1
24	23.9	38.5	23.1	37.2	9.10	2.77	1,610	149.6
25	23.1	37.2	22.5	36.2	2.90	0.88	3,062	284.5
26	22.5	36.2	21.0	33.8	4.70	1.43	6,514	605.2
27	21.0	33.8	19.2	30.9	7.50	2.29	4,703	436.9
28	19.2	30.9	17.4	28.0	3.75	1.14	2,244	208.5
29	17.4	28.0	16.2	26.1	5.50	1.68	2,993	278.1
30	16.2	26.1	15.0	24.1	7.47	2.28	3,409	316.7
31	15.0	24.1	13.1	21.1	8.90	2.71	5,466	507.8
32	13.1	21.1	12.6	20.3	6.06	1.85	4,871	452.5
33	12.6	20.3	12.1	19.5	6.92	2.11	10,677	991.9
34	12.1	19.5	10.4	16.7	6.45	1.97	11,196	1,040.1
35	10.4	16.7	8.9	14.3	11.63	3.54	11,623	1,079.8
36	8.9	14.3	7.3	11.7	15.02	4.58	12,742	1,183.8
37	7.3	11.7	7.0	11.3	3.73	1.14	5,364	498.3
38	7.0	11.3	6.3	10.1	5.97	1.82	8,584	797.5
39	6.3	10.1	5.7	9.2	6.94	2.12	11,382	1,057.4
40	5.7	9.2	4.8	7.7	6.47	1.97	7,505	697.2
41	4.8	7.7	4.0	6.4	6.83	2.08	18,544	1,722.8
42	4.0	6.4	3.7	6.0	9.00	2.74	12,042	1,118.7
43	3.7	6.0	2.6	4.2	13.00	3.96	15,002	1,393.7
44	2.6	4.2	1.3	2.1	21.00	6.40	12,978	1,205.7
45	1.3	2.1	1.0	1.6	22.00	6.71	18,590	1,727.1
46	1.0	1.6	0.7	1.1	22.00	6.71	13,068	1,214.1
47	0.7	1.1	0.3	0.5	22.00	6.71	16,800	1,560.8
48	0.3	0.5	0.1	0.2	22.00	6.71	18,700	1,737.3
49	0.1	0.2	0.0	0.0	17.00	5.18	15,946	1,481.4

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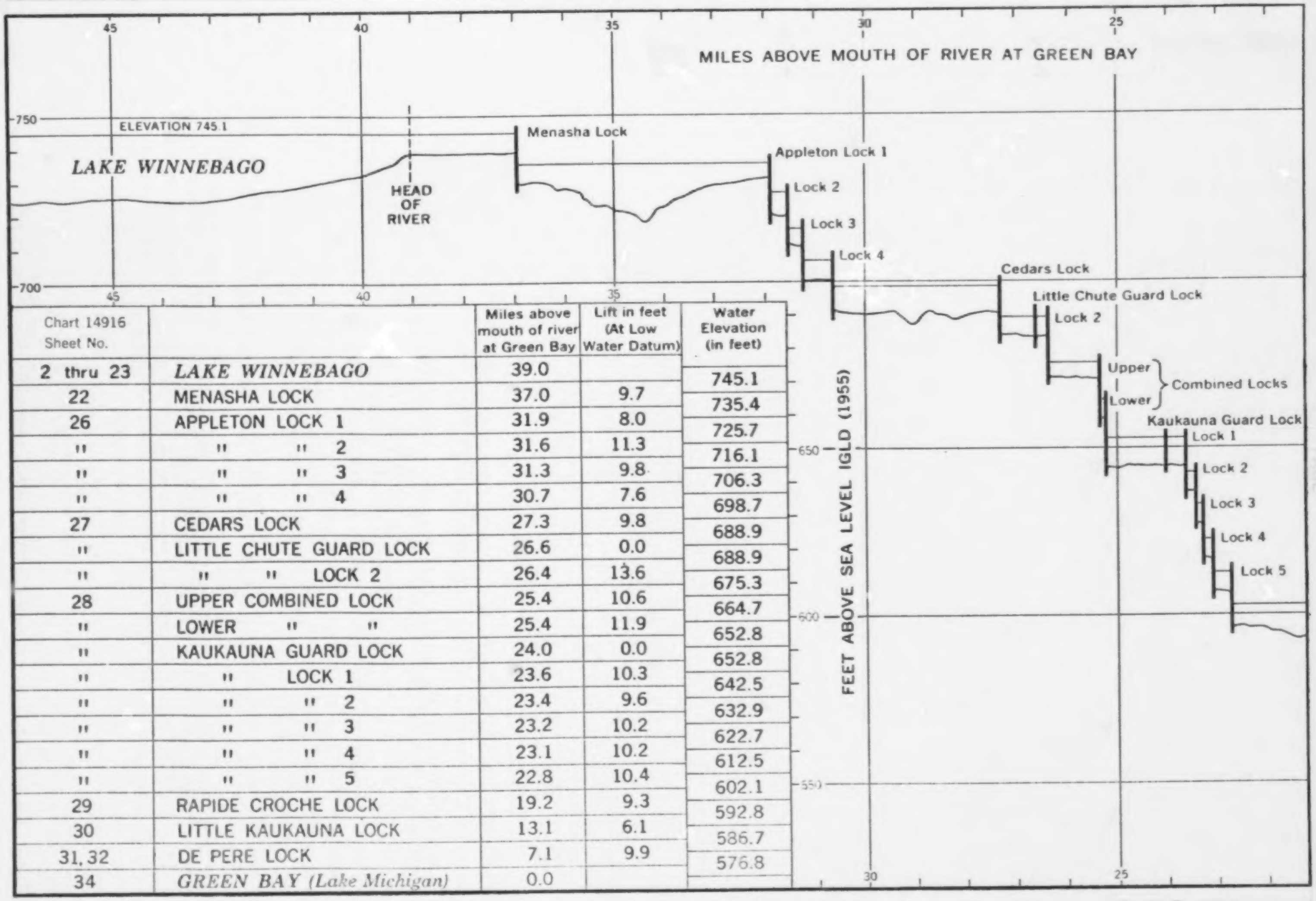
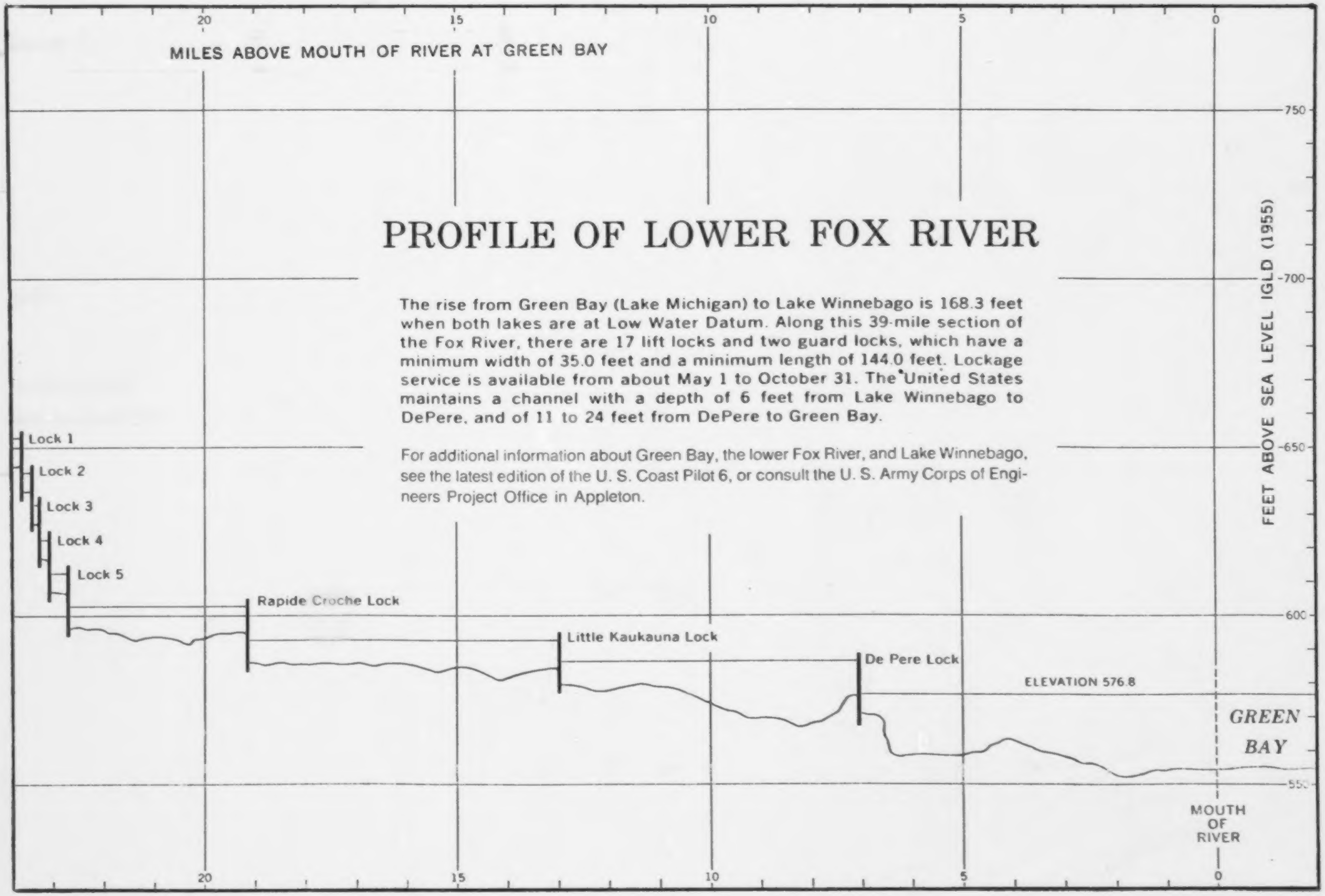


Chart 14916 Sheet No.		Miles above mouth of river at Green Bay	Lift in feet (At Low Water Datum)	Water Elevation (in feet)
2 thru 23	*LAKE WINNEBAGO*	39.0		745.1
22	MENASHA LOCK	37.0	9.7	735.4
26	APPLETON LOCK 1	31.9	8.0	725.7
"	" " 2	31.6	11.3	716.1
"	" " 3	31.3	9.8	706.3
"	" " 4	30.7	7.6	698.7
27	CEDARS LOCK	27.3	9.8	688.9
"	LITTLE CHUTE GUARD LOCK	26.6	0.0	688.9
"	" " LOCK 2	26.4	13.6	675.3
28	UPPER COMBINED LOCK	25.4	10.6	664.7
"	LOWER " "	25.4	11.9	652.8
"	KAUKAUNA GUARD LOCK	24.0	0.0	652.8
"	" LOCK 1	23.6	10.3	642.5
"	" " 2	23.4	9.6	632.9
"	" " 3	23.2	10.2	622.7
"	" " 4	23.1	10.2	612.5
"	" " 5	22.8	10.4	602.1
29	RAPIDE CROCHE LOCK	19.2	9.3	592.8
30	LITTLE KAUKAUNA LOCK	13.1	6.1	586.7
31, 32	DE PERE LOCK	7.1	9.9	576.8
34	*GREEN BAY (Lake Michigan)*	0.0		

Figure 5-3a. Streambed profile of the Lower Fox River (after National Ocean Survey Chart 14916, 1981).



PROFILE OF LOWER FOX RIVER

The rise from Green Bay (Lake Michigan) to Lake Winnebago is 168.3 feet when both lakes are at Low Water Datum. Along this 39-mile section of the Fox River, there are 17 lift locks and two guard locks, which have a minimum width of 35.0 feet and a minimum length of 144.0 feet. Lockage service is available from about May 1 to October 31. The United States maintains a channel with a depth of 6 feet from Lake Winnebago to DePere, and of 11 to 24 feet from DePere to Green Bay.

For additional information about Green Bay, the lower Fox River, and Lake Winnebago, see the latest edition of the U. S. Coast Pilot 6, or consult the U. S. Army Corps of Engineers Project Office in Appleton.

MILES ABOVE MOUTH OF RIVER AT GREEN BAY
20
15
10
5
0
FEET ABOVE SEA LEVEL IGLD (1955)
750
700
650
600
550
Lock 1
Lock 2
Lock 3
Lock 4
Lock 5
Rapide Croche Lock
Little Kaukauna Lock
De Pere Lock
ELEVATION 576.8
GREEN BAY
MOUTH OF RIVER

Figure 5-3b. Streambed profile of the Lower Fox River (continued).

estimated using the formula:

$$V = 1.1\ Q/A \qquad (5\text{-}1)$$

where V = velocity,
Q = volumetric flow rate, and
A = cross sectional area of channel.

The correction factor of 1.1 was chosen to match time of travel data on a similar river where a dye study was calculated. It is thought that the travel times were shorter than expected due to stagnant areas that added to the cross sectional area but did not have significant flow velocities.

The average river flow rates during the study periods are presented in Table 5-3. They are also contained in the computer data set.

TABLE 5-3. AVERAGE RIVER FLOW RATES DURING STUDY PERIODS (after Patterson, 1980).

Study Period			Average Flow	
			(m^3/s)	(cfs)
June	20-21	1972	63.71	2250
July	18-19	1972	56.35	1990
August	14-15	1972	55.78	1970
June	12	1973	356.37	12585
July	24-25	1973	65.13	2300
July	26	1975	52.53	1855
July	27	1975	57.20	2020
August	30	1976	33.98	1200
August	31	1976	33.27	1175
July	26	1977	44.32	1565
July	27	1977	43.89	1550

5-3-4 Climatological Data

Precipitation--

A record of precipitation during the study periods is not presented here since non-point inflows are not considered, and point inflows are meaured. However, the precipitation records may be obtained from the NOAA publication, "Climatological Data for Wisconsin."

Pan Evaporation--

Pan evaporation is not presented for the same reasons as precipitation.

Ambient Temperatures--

The computer data set contains records of the water temperatures during the studies, and ambient air temperatures are available from the same source as the precipitation records.

Insolation--

The daily insolation intensities and durations are of some interest since the Lower Fox River is considerably affected by algal activity. The solar radiation intensities are given in the computer data set in langleys per day, and the total number of daylight hours is also given.

Windspeed--

Since some sections of the river are broad and sluggish, wind speed can be important in determining reaeration. Windspeeds are given in the computer data set in m/s, and reaches where their use is recommended are indicated.

5-3-5 Sampling Techniques

Flow Rates--

River flows for the Lower Fox River are reported by the Corps of Engineers and published by the USGS. The flow rates are based on flows from the electrical generators and spillway of the Rapide Croche Dam and the operation of the river locks. The flow rates from the intakes and outfalls of the water treatment plants were derived from operator records.

Flow Velocities--

No time of travel studies have been performed on the Lower Fox River, and the flow velocities must be estimated from the flow rate to flow velocity relationship presented in Section 5-3-2. This relationship was derived from time of travel studies on a river similar to the Lower Fox River.

Insolation--

The solar radiation data were obtained from a number of sources. Most of the data presented in the computer data set were collected by the U.S. Forest Service in Rhinelander. However, some additional radiation data were obtained from the University of Wisconsin - Green Bay, the University of Wisconsin - Madison Soils Department, Entomology Department, and Agriculture Department, from the NOAA station at Madison, and from the airport at Wassau.

Windspeed--

Windspeed measurements were either made by the field survey crew using hand-held instruments, or were taken from the NOAA publication, "Climatological Data for Wisconsin."

5-4. RIVER QUALITY DESCRIPTION

5-4-1 Major Pollution Sources

Point Sources--

The Lower Fox River receives effluent from 12 sewage treatment plants and from 21 other sources, mostly papermills. The positions of the sources are given in Table 5-1 and are shown in Figure 5-2.

The list of water quality parameters measured in the headwaters of the river is given in Table 5-4, and the water quality and loading parameters measured in the tributaries and other point sources are listed in Table 5-5. The data values of these loading parameters are included in the computer data set as input to the QUAL-III model. These input data are formatted in a way that makes it very easy to read and understand the data. An explanation of the data format is included with the data set, and users should have no difficulty in abstracting the necessary data for use in other models.

One unusual feature of the data is the manner in which BOD has been calculated. The Wisconsin DNR analyzed effluent streams and divided the BOD into carbonaceous BOD (CBOD) and nitrogenous BOD (NBOD). The NBOD loads may be calculated from the loads of ammonia, nitrite and organic nitrogen which are given in the computer data set (the reaction rate constants are given in Section 5-4-2). CBOD is frequently modelled using a single term first order exponential decay equation. However, waste from pulp mills often contains a mix of organic carbon compounds with widely differing decay rates, and the Wisconsin DNR found that is was more accurate to model CBOD decay using a two term decay equation:

$$L(t) = L_1(1-e^{-K_{11}t}) + L_2(1-e^{-K_{12}t}) \qquad (5\text{-}2)$$

where $L(t)$ = ultimate CBOD exerted at time t (mg/l),
L_1 = fast term CBOD concentration (mg/l),
K_{11} = fast term CBOD decay rate coefficient (day^{-1}),
L_2 = slow term CBOD concentration (mg/l), and
K_{12} = slow term CBOD decay rate coefficient (day^{-1}).

The decay rate coefficients are given in Section 5-4-2.

Non-Point Sources--

Information on non-point loads is not included because the Wisconsin DNR found that non-point loads were insignificant by comparison to the point loads.

5-4-2 Biochemical Data

Biochemical Rate Constants--

The Wisconsin DNR used various reaction rate constants in their model of the Fox River. Some of the constants were found to be the same at locations and times, while others were variable. The report by Patterson (1980) gives values of the rate constants for each river reach. However, in this report the river is divided into 36 reaches instead of the 49 reaches described in the report by the Wisconsin DNR (1977) and given in Table 5-2. The locations of Patterson's reaches are given in Table 5-6, and the same reaches are referred to in Tables 5-8 and 5-9. The coefficients that Patterson (1980) used to model the river are given in Tables 5-7, 5-8 and 5-9. Those parameters which are the same for the whole river are given in Table 5-7, while parameters which change from reach tc reach are given in Table 5-8. Table 5-9 contains those parameters which change from reach to reach and also from year to year.

TABLE 5-4. WATER QUALITY PARAMETERS MEASURED IN HEADWATERS.

Parameter	Units
Flow	cfs
Temperature	°F
D.O. Concentration	mg/l
Fast term CBOD concentration	mg/l
Slow term CBOD concentration	mg/l
Chlorophyll A concentration	μg/l
Ammonia as N	mg/l
Nitrate as N	mg/l
Phosphate as P	mg/l
Organic nitrogen not in algae	mg/l

TABLE 5-5. WATER QUALITY PARAMETERS MEASURED IN EFFLUENTS AND TRIBUTARIES.

Parameter	Units
Fraction of treatment	-
Flow rate	cfs
Temperature	°F
D.O. concentration	mg/l
Fast term CBOD concentration	mg/l
Slow term CBOD concentration	mg/l
Chlorophyll A concentration	μg/l
Ammonia concentration as N	mg/l
Nitrite concentration as N	mg/l
Nitrate concentration as N	mg/l
Phosphate concentration as P	mg/l
Coliform, MPN or suspended solids	l^{-1}, mg/l
Organic nitrogen as N	mg/l

TABLE 5-6. REACH LOCATIONS USED IN TABLES 5-8 AND 5-9 (after Patterson, 1980).

Reach Number	Reach Name	Starting Point (mile)	Starting Point (km)	Ending Point (mile)	Ending Point (km)
1	Menasha Channel	40.0	64.4	39.0	62.8
2	Menasha Channel	39.0	62.8	37.9	61.0
3	Neenah Channel	39.7	63.9	38.8	62.4
4	Neenah Channel	38.8	62.4	38.3	61.6
5	West End LLBDM	38.3	61.6	37.8	60.8
6	Menasha Channel	37.8	60.8	37.4	60.2
7	Butte Des Morts	37.4	60.2	37.0	59.5
8	North End LLBDM	37.0	59.5	36.2	58.3
9	Stroebe Is.	36.2	58.3	35.0	56.3
10	Mud Creek	35.0	56.3	34.5	55.5
11	Old Rch. 10	34.5	55.5	34.2	55.0
12	Grignon Rapids	34.2	55.0	32.4	52.1
13	Appleton I	32.4	52.1	31.9	51.3
14	Appleton II	31.9	51.3	31.0	49.9
15	Appleton III	31.0	49.9	30.8	49.6
16	Telulah Park	30.8	49.6	30.0	48.3
17	Half of 16	30.0	48.3	28.7	46.2
18	Sunset Point Pk	28.7	46.2	27.5	44.3
19	Kimberly	27.5	44.3	26.8	43.1
20	Washington St. K.	26.8	43.1	26.5	42.6
21	Little Chute	26.5	42.6	25.9	41.7
22	Combined Locks	25.9	41.7	25.4	40.9
23	Kaukauna	25.4	40.9	24.4	39.3
24	Kankapot Cr.	24.4	39.3	23.1	37.2
25	Thilmany	23.1	37.2	22.5	36.2
26	Twenty 4	22.5	36.2	21.0	33.8
27	Rapid Croche	21.0	33.8	19.2	30.9
28	Wrightstown	19.2	30.9	17.4	28.0
29	Plum Creek	17.4	28.0	16.2	26.1
30	2nd Half of 27	16.2	26.1	15.0	24.1
31	Apple Creek	15.0	24.1	13.1	21.1
32	Little Rapids	13.1	21.1	12.6	20.3
33	Hickory Grove	12.6	20.3	12.1	19.5
34	Old Rch. 31	12.1	19.5	10.4	16.7
35	First Half of 32	10.4	16.7	8.9	14.3
36	De Pere Dam	8.9	14.3	7.3	11.7

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TABLE 5-7. BIOCHEMICAL COEFFICIENTS WHICH ARE CONSTANT FOR THE LOWER FOX RIVER (Patterson, 1980).

Coefficient	Value
Oxygen uptake by ammonia nitrification	= 3.43 mg O_2/mg N
Oxygen uptake by nitrite nitrification	= 1.12 mg O_2/mg N
Maximum denitrification	= 0.40 day^{-1}
Fixed portion of organic nitrogen hydrolysis rate	= 0.05 day^{-1}
Oxygen production by algae growth	= 2.00 mg O_2/mg algae
Oxygen uptake by algae respiration	= 1.50 mg O_2/mg algae
Saturating light level for algae growth	= 0.40 langleys/minute
Nitrogen content of algae	= 0.080 mg N/mg algae
Phosphorus content of algae	= 0.012 mg P/mg algae
Nitrogen half saturation concentration	= 0.020 mg/l
Phosphorus half saturation concentration	= 0.005 mg/l
Fraction of settled algae biomass that decays for oxygen consumption	= 0.56
NH_3-N decay rate	= 0.10 day^{-1}
NO_2-N decay rate	= 2.0 day^{-1}
Sediment source for NH_3	= 0.0 mg/m^2-day
Sediment source for PO_4	= 0.0 mg/m^2-day
Chlorophyll-a to algae conversion	= 6.0 units/mg
Algae settling rate	= 0.25 ft/day
Organic-N settling rate	= 0.30 ft/day

TABLE 5-8. BIOCHEMICAL COEFFICIENTS WHICH VARY WITH POSITION IN THE LOWER FOX RIVER (Patterson, 1980).

Reach Number*	Fast Term BOD decay Rate (day^{-1})	Slow Term BOD decay Rate (day^{-1})	Reaeration Formula Used**	Algal Org-N Hydrolysis Rate	Light Extinction Coeff. (ft^{-1})
1	.100	.050	1	.0030	.30
2	.100	.050	1	.0030	.30
3	.100	.050	1	.0030	.30
4	.100	.050	1	.0030	.30
5	.300	.100	3	.0030	.50
6	1.20	.300	3	.0030	.40
7	1.20	.300	3	.0030	.40
8	1.20	.300	3	.0022	.40
9	1.20	.300	3	.0022	.40
10	.500	.300	1	.0022	.40
11	.500	.300	1	.0022	.40
12	.500	.300	1	.0022	.40
13	.500	.300	1	.0022	.40
14	.500	.300	1	.0022	.40
15	.500	.300	2	.0022	.40
16	.700	.300	1	.0022	.40
17	1.00	.300	1	.0022	.40
18	1.00	.300	1	.0022	.40
19	1.00	.300	1	.0022	.40
20	1.00	.300	1	.0022	.40
21	1.00	.300	1	.0022	.40
22	1.00	.300	1	.0022	.60
23	1.00	.300	1	.0022	.40
24	1.00	.300	1	.0022	.40
25	1.00	.300	1	.0022	.40
26	.800	.300	1	.0022	.40
27	.800	.300	1	.0022	.40
28	.800	.300	1	.0022	.40
29	.800	.300	1	.0022	.40
30	.800	.300	1	.0022	.40
31	.800	.300	1	.0022	.40
32	.600	.300	1	.0022	.40
33	.600	.300	1	.0022	.40
34	.600	.300	3	.0022	.40
35	.600	.300	3	.0022	.40
36	.600	.300	3	.0022	.40

* See Table 5-6 for reach locations

** 1 = O'Connors and Dobbins (1958)
2 = Owens, Edwards and Gibbs (1964)
3 = An equation based on windspeed. See Section 5-4-2.

TABLE 5-9. BIOCHEMICAL COEFFICIENTS WHICH VARY WITH TIME AND POSITION IN THE LOWER FOX RIVER (after Patterson, 1980).

	BOD Settling Rate (ft/day)			Maximum Phytoplankton Growth Rate (day^{-1})			Phytoplankton Respiration Rate (day^{-1})		
Reach Number*	1972-1976	1977	1978 + Prediction	1972-1976	1977	1978 + Prediction	1972-1976	1977	1978 + Prediction
1	00.00	00.00	00.00	2.00	2.00	2.00	.100	.100	.100
2	00.00	00.00	00.00	2.00	2.00	2.00	.100	.100	.100
3	00.00	00.00	00.00	2.00	2.00	2.00	.100	.100	.100
4	00.00	00.00	00.00	2.00	2.00	2.00	.100	.100	.100
5	01.00	00.00	00.00	2.00	2.00	2.00	.100	.100	.100
6	01.00	00.00	00.00	2.00	2.00	2.00	.100	.100	.100
7	01.00	00.00	00.00	2.00	2.00	2.00	.100	.100	.100
8	00.00	00.00	00.00	2.00	2.00	2.00	.100	.100	.100
9	00.00	00.00	00.00	2.00	2.00	2.00	.100	.100	.100
10	00.00	00.00	00.00	2.00	2.00	2.00	.100	.100	.100
11	00.00	00.00	00.00	2.00	2.00	2.00	.100	.100	.100
12	00.00	00.00	00.00	2.00	2.00	2.00	.100	.100	.100
13	00.00	00.00	00.00	1.90	1.90	2.00	.100	.100	.100
14	00.00	00.00	00.00	1.90	1.90	2.00	.100	.100	.100
15	00.00	00.00	00.00	1.90	1.90	2.00	.120	.120	.100
16	00.00	00.00	00.00	1.90	1.90	2.00	.120	.120	.100
17	01.00	01.00	00.00	1.90	1.90	2.00	.120	.120	.100
18	01.00	01.00	0. 00	1.90	1.90	2.00	.120	.120	.100
19	01.00	01.00	00.00	1.90	1.90	2.00	.120	.120	.100
20	01.00	01.00	00.00	1.90	1.90	2.00	.120	.120	.100
21	01.00	01.00	00.00	1.90	1.90	2.00	.130	.130	.100
22	01.00	00.00	00.00	1.80	1.80	2.00	.130	.130	.100
23	01.00	00.00	00.00	1.80	1.80	2.00	.130	.130	.100
24	01.00	00.00	00.00	1.80	1.80	2.00	.100	.100	.100
25	01.00	00.00	00.00	1.80	1.80	2.00	.100	.100	.100
26	00.50	00.00	00.00	1.80	1.80	2.00	.100	.100	.100
27	00.00	00.00	00.00	1.90	1.90	2.00	.100	.100	.100
28	00.00	00.00	00.00	1.90	1.90	2.00	.100	.100	.100
29	00.00	00.00	00.00	1.90	1.90	2.00	.100	.100	.100
30	00.00	00.00	00.00	1.90	1.90	2.00	.100	.100	.100

(continued)

* See Table 5-6 for reach locations.

TABLE 5-9 (concluded)

Reach Number *	BOD Settling Rate (ft/day)			Maximum Phytoplankton Growth Rate (day^{-1})			Phytoplankton Respiration Rate (day^{-1})		
	1972-1976	1977	1978 + Prediction	1972-1976	1977	1978 + Prediction	1972-1976	1977	1978 + Prediction
31	00.00	00.00	00.00	1.90	1.90	2.00	.100	.100	.100
32	00.00	00.00	00.00	2.40	2.40	2.40	.100	.100	.100
33	00.00	00.00	00.00	2.40	2.40	2.40	.100	.100	.100
34	00.00	00.00	00.00	2.40	2.40	2.40	.100	.100	.100
35	00.00	00.00	00.00	2.40	2.40	2.40	.100	.100	.100
36	00.00	00.00	00.00	2.40	2.40	2.40	.100	.100	.100

* See Table 5-6 for reach locations.

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It should be noted that the values of these parameters are given at 20°C. Physical processes such as settling rates for algae, organic nitrogen and BOD are assumed to be independent of temperature. However, with the exception of algal hydrolysis of organic nitrogen, denitrification, benthic source rates of ammonia and phosphorus, and slow term BOD decay (K_{11}), all biochemical reaction rates are assumed to be temperature dependent. It is common to adjust reaction rates by using the equation:

$$K(T) = K_{20}\theta^{T-20} \qquad (5\text{-}3)$$

where K(T) = decay or reaction rate at T°C,
K_{20} = decay or reaction rate at 20°C,

θ = adjustment coefficient, and
T = temperature, °C.

For most reactions a constant value of $\theta = 1.047$ can be used. However, in the equations for biological and sediment oxygen demand θ is assumed to be a function of temperature:

$$\theta_{BOD} = 1.1776 - 0.00649T \quad (\text{for } T \leq 20°\text{C}) \qquad (5\text{-}4)$$

$$\theta_{BOD} = 1.047 \quad (\text{for } T \geq 20°\text{C})$$

$$\theta_{SOD} = 1.1 - 0.00175T \quad (\text{for all } T) \qquad (5\text{-}5)$$

The nitrification reaction rates are corrected for temperature using a different form of equation:

$$K(T) = K_{20}\ (1.2034)(0.877)^{T-22} \quad (\text{for } T \geq 22°\text{C}) \qquad (5\text{-}6)$$

$$K(T) = K_{20}\ (1.097)^{T-20} \quad (\text{for } T \leq 22°\text{C}) \qquad (5\text{-}6)$$

River Quality Sampling--

The Wisconsin DNR made 11 intensive water sampling surveys on the Lower Fox River between 1972 and 1977. The surveys were generally made over a one or two day period under steady low flow conditions during July or August. Up to 49 stations were used, and on some surveys samples were taken from several different depths and transverse positions at each station. The six earliest surveys from 1972 to 1975 are of limited usefulness because the only quality parameters measured are dissolved oxygen and temperature. However, the five following surveys from 1975 to 1977 contain more information, and three of the five give extensive information on nutrient levels in the river.

The STORET codes and positions of the Wisconsin DNR stations are given in Table 5-10. The survey data described in this section are not included on the computer data set since they may readily be obtained from the EPA STORET computer data base. STORET also contains data measured in the Lower Fox River at times other than those mentioned in this report, and some of this information might be useful when making estimates for unknown parameters in the river.

Reaeration--

Reaeration in the Lower Fox River is caused by various effects. One cause is the turbulence induced as the water flows over weirs and spillways

TABLE 5-10. LOCATION OF LOWER FOX RIVER STORET STATIONS (Wisconsin DNR, 1977).

Station Number	River Mile	River Kilometer	Latitude	Longitude	Description
713060	39.2	63.1	44°12'13.4"	88°26'16.0"	Menasha Channel at Water Plant
713057	38.9	62.6	44°11'12.0"	88°27'20.0"	Neenah Channel at Oak Street
713058	38.6	62.1	44°11'22.0"	88°27'34.0"	Neenah Channel at Commercial Street
713059	38.1	61.3	44°11'42.6"	88°28'19.8"	At Kimberly-Clark Lakeview
713061	37.6	60.5	44°12' 3.0"	88°27'53.0"	Manasha Channel at Outlet
713062	37.5	60.4	44°12'12.5"	88"28' .0"	Little Lake Butte des Morts RR Bridge
713063	36.3	58.4	44°12'47.0"	88°27'42.0"	Middle of Little Lake Butte des Morts
713064	34.7	55.8	44°14'11.5"	88°26'57.6"	At Strobe Island Power Lines
453049	34.0	54.7			
453050	32.4	52.1	44°15'11.6"	88°24'38.8"	Above Vulcan Dam, Appleton
453051	32.2	51.8	44°15'12.0"	88°24'30.0"	At RR Bridge Below Vulcan Dam
453052	31.7	51.0	44°15'31.0"	88°23'50.0"	At Lawe Street, Appleton
453053	30.8	49.6	44°15'31.0"	88°23'27.0"	Below Lower Dam, Appleton
453054	30.6	49.2	44°15'46.0"	88°23'15.0"	100 Yards Below Consolidated Papers, Appleton
453055	30.4	48.9	44°15'57.0"	88°23' .0"	At Bend Below Consolidated Papers, Appleton
453056	30.0	48.3	44°16' 5.0"	88°22'29.0"	Above Appleton STP
453057	29.3	47.2	44°16'34.0"	88°21'56.0"	Between Appleton STP and Boat Landing
453058	28.3	45.5	44°16'33.0"	88°20'43.0"	At Kimberly Boat Landing
453059	27.6	44.4	44°16'41.0"	88°20' 4.0"	Above Mid Tech Kimberly Dam
453060	27.0	43.4	44°16'39.0"	88°19'13.0"	Near County Trunk Highway N, Kimberly
453061	25.8	41.5	44°16'20.8"	88°18' .0"	At Combined Locks Mill Tailrace
453062	25.3	40.7	44°16'28.0"	88°17'21.0"	At Little Chute Sanitorium
453063	24.4	39.3	44°16'52.7"	88°16'50.1"	At Kaukauna Boat Landing
453064	23.9	38.5	44°16'52.0"	88°16'14.0"	Above Upper Kaukauna Dam
453065	23.0	37.0	44°16'52.7"	88°14'58.0"	Adjacent to Thilmany, Above Lagoon
453066	22.4	36.0	44°17' .0"	88°14'30.0"	Near Thilmany Lagoon Outfall
453067	20.8	33.5	44°18' 4.4"	88°13'30.0"	At Bend Near Buoy 27
453068	19.2	30.9	44°18'56.0"	88°11'59.0"	Above Rapide Croche Dam
453069	18.8	30.3	44°18'57.0"	88°11'24.0"	Below Rapide Croche Dam
053204	17.5	28.2	44°19'33.0"	88°09'57.0"	At Plum Creek, Wrightstown
053205	15.1	24.3	44°21'18.0"	88°08'46.0"	At Apple Creek, Near Wrightstown

(continued)

TABLE 5-10 (concluded)

Station Number	River Mile	River Kilometer	Latitude	Longitude	Description
053206	13.2	21.2	44°22'45.0"	88° 7'25.0"	Above Little Rapids Dam
053207	12.6	20.3	44°22'47.0"	88° 7'23.0"	Below Little Rapids Dam
053208	12.2	19.6	44°23'27.0"	88° 7' 9.0"	At Hickory Grove Sanitorium
053209	10.4	16.7	44°24'41.3"	88° 5'42.3"	At Blue-roofed barn, above DePere
053210	7.3	11.7	44°26'52.0"	88° 3'51.0"	Above DePere Dam
053211	7.0	11.3	44°27' 6.0"	88° 4' 8.0"	Below DePere Dam, At Locks
053212	6.3	10.1	44°26'53.8"	88° 3'43.9"	At DePere STP
053213	5.7	9.2	44°28' 9.0"	88° 3'20.0"	At Ashwaubenon Creek
053214	4.8	7.7	44°28'50.0"	88° 2'49.0"	At Dutchman Creek
053215	4.0	6.4	44°29' 1.5"	88° 1'43.1"	At Reimer's Meats, Green Bay
053216	3.3	5.3	44°29'26.5"	88° 1'56.0"	At Fort Howard Slip
053217	2.3	3.7	44°30'33.4"	88° 1'20.7"	At Mason Street, Green Bay
053218	1.8	2.9	44°30'56.1"	88° 1'10.3"	At Walnut St., Green Bay
053219	1.6	2.6	44°31' 5.0"	88° 0'59.0"	At Main St., Green Bay
053220	1.3	2.1	44°31'15.0"	88° 0'43.0"	Above East River
053221	0.9	1.4	44°31'26.1"	88° 0'26.4"	At Proctor & Gamble, Green Bay
053222	0.2	0.3	44°32'12.5"	88° 0'17.0"	At Green Bay Yacht Club
053223	0.0	0.0	44°32'22.5"	88° 0'15.0"	At Mouth, Green Bay

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or through electrical generating turbines. Data for these localized sources of reaeration are presented in Table 5-11.

TABLE 5-11. MEASURED LOCALIZED HYDRAULIC REAERATION PARAMETERS.

Parameter	Unit
Height of spillway or waterfall	ft
Coefficient of spillway aeration	ft^{-1}
Fraction of total flow going over spillway or waterfall	--
Coeficient of turbine aeration	--

Reaeration is also caused by oxygen transfer at the surface of the water. There are various equations available for the calculation of this reaeration, but few are universally applicable. Depending on the reach, the Wisconsin DNR used one of three methods: O'Connor and Dobbins (1958), Owens, Edwards and Gibbs (1964), or a method of their own based on wind velocity. The Wisconsin DNR equation is:

$$K_2 = \frac{(1.0 + \cosh(xxx)) \times 86400}{(2.0 \times DD \times \sinh(xxx))(DDM \times SSS)^{1/2}} \qquad (5\text{-}7)$$

where $xxx = (XLF)^2 \times SSS/DDM$,
$SSS = 0.04 \times vel/DD$,
$DDM = 1.806 \times 10^{-9}$,
$DD = 0.3048 \times$ river depth, m,
$XLF = [15.7735859 - (0.57835501 \times vel)]^2 \times 10^{-6}$ (for vel $\geq$ 4.0 m/s),
$XLF = 0.00018118$ (for vel < 4.0 m/s), and
vel = windspeed, m/s.

The calculation based on wind velocity was used for wide slow moving stretches of the river. The coefficients for all three reaeration equations are contained in the computer data set, and the equation recommended for each reach is shown in Table 5-8.

5-4-3 Measurement Listing

The water quality parameters measured in headwaters, effluents and tributaries are listed in Tables 5-4 and 5-5. These data measurements are given in the computer data set, which also contains data on water withdrawal and effluent flow rates, windspeeds, insolation, Mannings roughness coefficients, and average reach depths and cross-sectional areas.

The parameters measured in the intensive river quality surveys are listed in Table 5-12, and these data can be retrieved from STORET.

5-4-4 Sampling Techniques

The data base report by Wisconsin DNR (1977) does not give a detailed description of sampling techniques. For some of the surveys only field measurements were made, while in the others both field and laboratory measurements were made. The field measurements were: dissolved oxygen concentration and temperature (measured with a YSI model 54 D.O. meter), conductivity (measured with a Chemtrix Type 70 Conductivity Meter), pH (measured with an AMI 707-B pH meter), and Secchi depth (measured with a standard 6 inch Secchi disk).

Information on the laboratory analyses is not provided, but may be deduced from the STORET parameter codes used to describe the parameters. Each STORET parameter code applies to a particular type of standard laboratory analysis.

5-5. COMPUTER DATA SET

The computer data set contains the parameters listed in Tables 5-4 and 5-5, and it also contains information on withdrawal and effluent flow rates, windspeeds, insolation, Mannings roughness coefficients, and average reach depths and cross-sectional areas.

The computer data set includes the intensive river survey data from 1975 through 1977, but not the data which were measured prior to 1975. These data may be retrieved from the EPA STORET data base using the station code numbers given in Table 5-10. The parameters measured during these intensive river surveys are listed in Table 5-12.

5-6. REFERENCES

1. Leung P-S. K. and Sell, N. J., "Effect of the Paper Industry on the Water Quality of the Lower Fox River," Water Resources Bulletin, AWRA, Vol. 18, No. 3, June 1982, pp. 495-502.

2. National Ocean Survey, "Lake Winnebago and Lower Fox River," Chart 14916, 6th Ed., U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Washington, DC, July 1981.

3. O'Conner, D. J., and Dobbins, W. E., "Mechanism of Reaeration in Natural Streams," Transactions, ASCE, Vol. 123, Paper No. 2934, 1958, pp. 641-684.

4. Owens, M., Edwards, R. W., and Gibbs, J. W., "Some Reaeration Studies in Streams," International Journal of Air and Water Pollution, Oxford, England, Vol. 8, No. 819, September 1964, pp. 469-486.

5. Patterson, D. J., Epstein, E., and McEvoy, J., "Water Pollution Investigation: Lower Green Bay and Lower Fox River," EPA-905/9-74-017 (NTIS PB 245 615), Environmental Protection Agency, Chicago, IL, June 1975.

TABLE 5-12. PARAMETERS MEASURED DURING INTENSIVE RIVER SURVEYS.

Survey Date	Parameters Measured
June 20-21, 1972	Time, depth, D.O., temperature
July 18-19, 1972	Time, depth, D.O., temperature
August 14-15, 1972	Time, depth, D.O., temperature
June 12, 1973	Time, depth, D.O., temperature
July 24-25, 1973	Time, depth, D.O., temperature
July 26, 1975	Time, depth, D.O., temperature, Secchi depth
July 27, 1975	Time, depth, D.O., temperature, Secchi depth, COD, total solids, suspended solids, volatile suspended solids, total-P, soluble-P, organic-N, ammonia-N, nitrate+nitrite-N, uncorrected and corrected chlorophyll-a
August 30, 1976	Time, depth, D.O., temperature, Secchi depth, pH, specific conductivity
August 31, 1976	Time, depth, D.O., temperature, Secchi depth, pH, conductivity, BOD_6, total solids, volatile total solids, suspended solids, volatile suspended solids, total-P, organic-N, ammonia-N, nitrite+nitrate-N, uncorrected and corrected chlorophyll-a
July 26, 1977	Time, depth, D.O., temperature, Secchi depth, pH, specific conductivity
July 27, 1977	Time, depth, D.O., temperature, Secchi depth, pH, specific conductivity, BOD_5, total solids, total volatile solids, total suspended solids, total-P, organic-N, ammonia-N, nitrate+nitrite-N, uncorrected and corrected chlorophyll-a

6. Patterson, D., "Water Quality Modelling of the Lower Fox River for Wasteload Allocation Development," Wisconsin Department of Natural Resources, Bureau of Water Quality Evaluation Section, Madison, WI, January 1980.

7. Weckwerth, H. W., and Fenske, B. A.,"Automatic Water Quality Monitoring of the Fox and Wisconsin Rivers 1972-1981," Wisconsin Department of Natural Resources, Water Quality Evaluation Section, Madison, WI, November 1982.

8. Wisconsin Department of Natural Resources," State of Wisconsin Wasteload Allocation for Lower Fox River Part I -- Data Base for River Modeling of Water Quality," Wisconsin Department of Natural Resources, Division of Environmental Standards, Water Quality Evaluation Section, Madison, WI, 1977.

9. Wisconsin Department of Natural Resources, "QUAL-III Water Quality Model Documentation," Wisconsin Department of Natural Resources, Water Quality Evaluation Section, Madison, WI, November 1979.

SECTION 6

LAKE OKEECHOBEE

6-1. INTRODUCTION

Lake Okeechobee is situated in South Florida north of the Everglades and west of West Palm Beach. Its area is 706 mi^2 (1828 km^2), which makes it the second largest freshwater lake in the United States after Lake Michigan. The lake is surrounded by a dike built by the Corps of Engineers to protect the surrounding areas from flooding caused by hurricanes. The dike was completed in 1937, and raised to the 40 foot MSL level between 1946 and 1964. Inflows and outflows are controlled as they pass through the dike so that the lake level can be regulated according to a schedule developed by the South Florida Water Management District and the Army Corps of Engineers. Despite this, the water budget for the lake is difficult to calculate because of problems in determining the effects of precipitation, evaporation and interactions with groundwater.

The lake is generally considered to be in a eutrophic condition, and data have been collected by many groups at intervals since 1940. The data presented here are from an intensive survey of nutrients and conservative substances performed from April 1973 to March 1980. During this period water quality in the lake and in its inflows and outflows were sampled at biweekly to monthly intervals.

6-2. SOURCE LITERATURE

Lake Okeechobee is one of the most studied lakes in Florida and represents a key component of the hydrology of the southern part of the state. An extensive bibliography of literature related to water quality studies in the lake may be found in a recent report by Brezonik et al. (1983b). A useful geological and physical description of the lake is given by Brooks (1974). Although eutrophication models have been applied by several groups (e.g., Baker et al., 1981), more detailed water quality models are somewhat less common; examples include efforts by Gayle (1975), Liggett et al. (1978) and Brezonik et al. (1983b). MacGill et al. (1976) summarize several studies up to 1976.

Operational responsibility for the lake resides with the Jacksonville District Corps of Engineers and with the South Florida Water Management District in West Palm Beach. Much specific information is available from both groups.

The vast majority of the information presented here was taken from a report of the South Florida Water Management District by Federico et al. (1981), which presents a good overview of the available data between 1973 and 1980.

6-3. WATERSHED DESCRIPTION

6-3-1 Study Area

Lake Okeechobee is situated in South Florida between the coordinates 27°21'N and 26°40'N, and 81°37'W and 81°08'W. The natural drainage patterns to the lake have been made more efficient by a succession of drainage projects which have raised the total watershed area from 4000 mi^2 (10,360 km^2) to 4600 square miles (11,910 km^2). The lake's drainage basins are shown in Figure 6-1.

The lake is surrounded by the Hoover Dike which was built on the 15 ft MSL contour, and rises to 40 ft MSL. The dike encloses an area of 706 mi^2 (1,829 km^2). All inflows and outflows except Fisheating Creek are controlled as they pass through the dike so that the lake stage can be regulated to protect against flooding. The natural direction of drainage is to the south, but large pumps have been installed so that the southern drainage basins can be used for inflow and outflow. The littoral zone of the lake covers about 150 mi^2 (390 km^2). The inflows and outflows to the lake and the littoral zone are shown in Figure 6-2.

Almost all of the lake's watershed is used for agricultural purposes. The land to the north and northwest is mostly used for cattle and dairy farming, while the areas to the south and east are mostly croplands. Extensive land use data are provided in the report by Federico et al. (1981).

6-3-2 Hydrologic Data

Point Inflows and Outflows--

All point inflows and outflows except Fisheating Creek are controlled as they pass through the Hoover Dike. The drainage basins to the north drain naturally into the lake, while those to the south and southeast drain naturally away from the lake. The southern and southeastern drainage basins have been converted to drain into or out of the lake by the addition of large pumping stations. The point inflows and outflows are shown in Figure 6-2.

Non-Point Inflows and Outflows--

Interactions with groundwater are not well understood or quantified. Since the lake is completely surrounded by the Hoover Dike, the only other non-point flow is seepage through the dike. It is estimated that there is an outflow of 0.72 cfs/mile caused by seepage through the dike (Shaw, 1980). The dike is 100 mi (161 km) long.

Lake Stage Regulation--

The maximum stage of Lake Okeechobee is regulated by the Corps of Engineers to provide flood protection. The maximum stage of the lake is different during the wet and dry seasons, and several different regulation schedules were used during the study period. The regulation schedules and the actual lake stages are shown in Figure 6-3.

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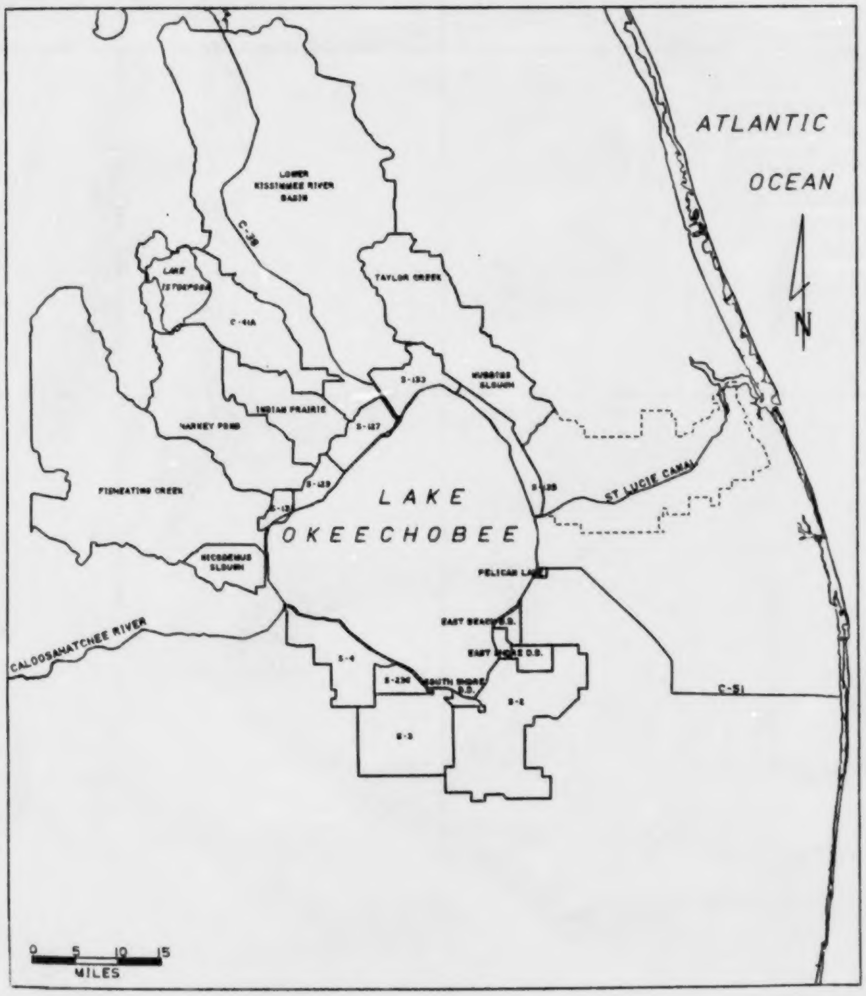
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FISHEATING CREEK
LAKE
OKEECHOBEE
NICODEMUS SLOUGH
PELICAN LAKE
EAST BEACH D.D.
EAST SHORE D.D.
CALOOSAHATCHEE RIVER
S-4
S-236
SOUTH SHORE D.D.
S-2
S-3
C-51
0 5 10 15
MILES

Figure 6-1. Lake Okeechobee surface water drainage basins (after Federico et al., 1981). Areas designated by dashed lines contribute only small amounts of water at irregular intervals. Drainage basins south of the lake have been added by man. The upper Kissimmee Basin also drains to the lake but is not shown.

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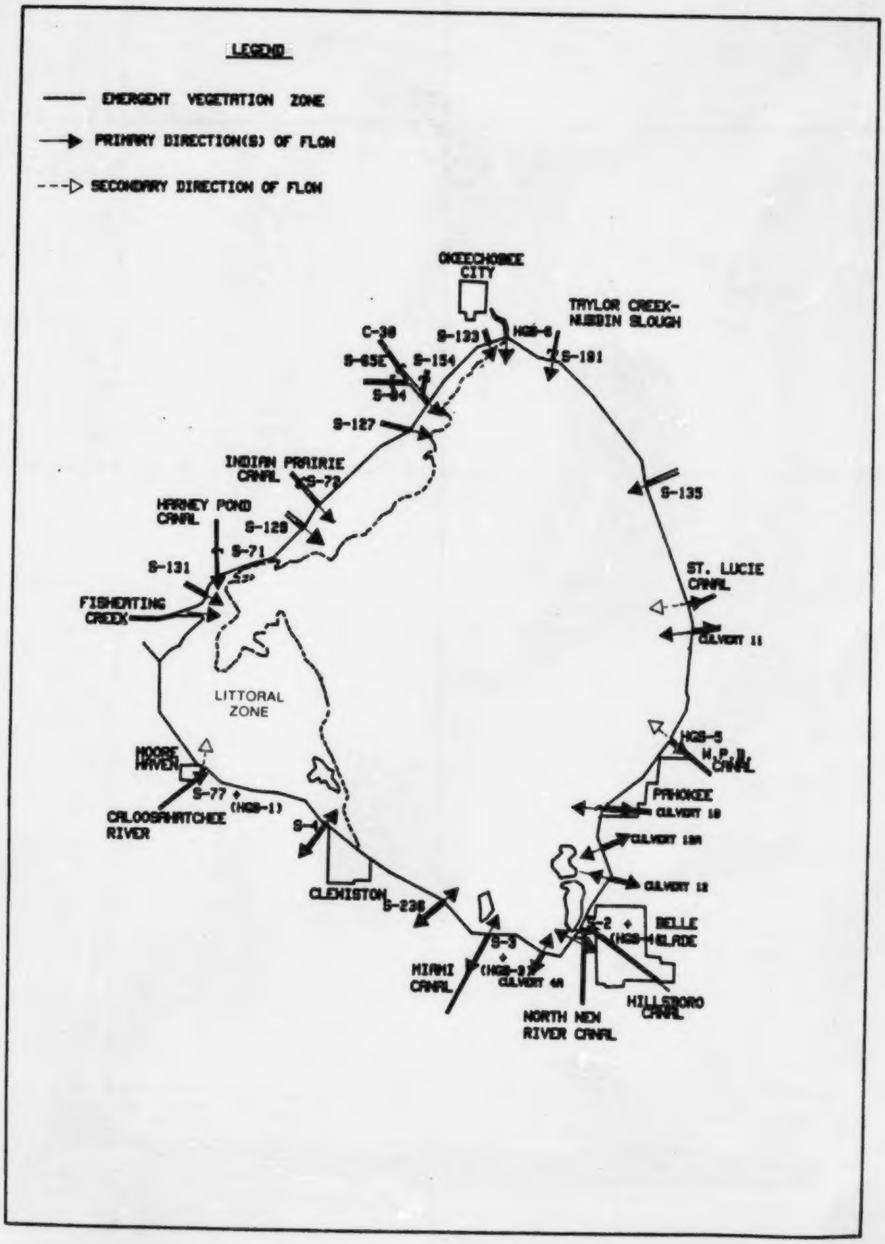
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C-38
S-65E
S-154
S-84
S-127
INDIAN PRAIRIE CANAL
S-72
HARNEY POND CANAL
S-129
S-71
S-131
FISHEATING CREEK
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ST. LUCIE CANAL
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CLEWISTON
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HGS-5
H.P.B. CANAL
PAHOKEE
CULVERT 10
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CULVERT 12
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BELLE GLADE
S-3
(HGS-3)
CULVERT 4A
MIAMI CANAL
NORTH NEW RIVER CANAL
HILLSBORO CANAL

Figure 6-2. Inflows and outflows to Lake Okeechobee (after Federico et al., 1981).

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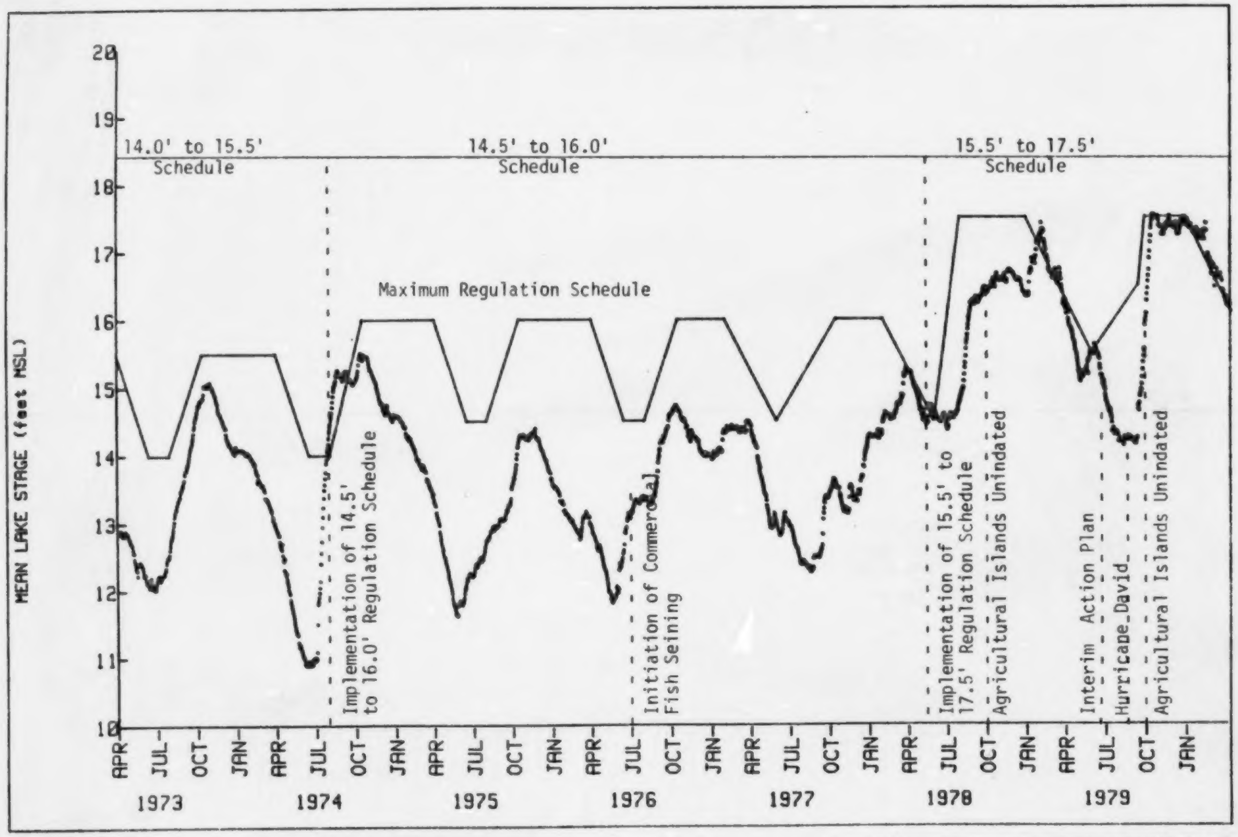

Figure 6-3. Mean daily lake stage in Lake Okeechobee (after Federico et al., 1981).

Water Budget--

Surface water inflows and outflows all pass through hydraulic structures in the Hoover Dike where they are gaged. Seepage through the dike can be estimated (see above) and is reponsible for about 1.7% of the water lost from the lake. The water budget is rendered uncertain by the difficulty of estimating the effects of precipitation, evaporation and groundwater. The lake is large enough to cause local variations in climate, so that measurements of precipitation and evaporation on land near the lake are not necessarily representative of conditions away from the shoreline (Riebson et al., 1974). Since precipitation contributes about 39% of the inflow to the lake and evaporation accounts for about 66% of the water loss, uncertainties in these two parameters can have a major effect on the water budget.

The Corps of Engineers reports a monthly water budget for the lake. The change in storage, as calculated from estimates of inflow and outflow, is compared with the actual change in storage indicated by lake stage. The annual water budgets for Lake Okeechobee calculated by the Corps of Engineers are presented in Table 6-1. Generally, the water budget tends to overestimate the increase in storage, so that additional water loss must be ascribed to sinks such as groundwater. The largest error was a 12.6% overestimate of storage in 1973. The average error over the seven years of the study was a 4% overestimate of storage. The annual percentage errors are given in Table 6-2.

6-3-3 Hydraulic Data

Bathymetric Data--

A bathymetric chart of Lake Okeechobee is shown in Figure 6-4, and the relationship among stage, area and volume is provided in Figure 6-5. A detailed bathymetric chart of the lake is available as Nautical Chart 11428 from the National Ocean Survey of NOAA. The mean annual values of lake stage, depth, surface area and volume are given in Table 6-3.

Residence Time--

The average residence time of water in a lake under steady state conditions can be calculated as the lake volume divided by the rate of water outflow. However, water lost by evaporation does not carry nutrients, so the residence time with respect to nutrients is calculated by excluding evaporation from the outflows. The annual average residence times (τ) calculated in this way are presented in Table 6-3.

Hydraulic Loading Rate--

The hydraulic loading rate (q_s) is defined as the rate of surface water inflow divided by the surface area of the lake. It represents the rate at which the lake surface would rise in the absence of outflows, evaporation and precipitation. The annual average hydraulic loading rates are given in Table 6-3.

6-3-4 Climatological Data

The climatological data for Lake Okeechobee are not presented because the water budget for the lake has already been calculated. The data sources

TABLE 6-1. ANNUAL WATER BUDGETS FOR LAKE OKEECHOBEE (ACRE-FEET) (after Federico et al., 1981).

Inflows:	1973 2/	1974	1975	1976	1977	1978	1979	1973-79 Avg.
N.N.R. & Hills.C (S-2)	154,092	207,708	318,447	205,499	213,347	200,173	71,892	195,880
Miami C. (S-3)	21,567	42,812	76,545	46,582	83,934	69,512	49,181	55,733
S-4 1/	-	29,249	26,575	23,558	44,645	50,956	34,338	34,887
Harney Pond C. (S-71)	154,893	171,079	82,170	99,935	140,083	295,688	245,018	169,838
Indian Prairie C(S-72)	24,367	43,304	7,504	20,484	34,753	72,116	59,445	37,425
Kissimmee R (S-65E)	1,028,913	1,442,038	838,503	1,157,951	520,423	1,297,681	1,231,434	1,073,849
S-84	232,553	211,044	87,290	57,644	11,974	207,740	176,167	140,630
Fisheating Creek	151,627	288,417	105,736	147,977	126,448	197,368	379,569	203,449
S-127	4,850	12,950	466	3,061	7,968	13,438	33,468	10,886
S-129	6,032	12,500	944	10,602	8,190	14,773	25,135	11,168
S-131	1,624	9,035	674	6,044	4,443	7,149	7,970	5,277
Taylor Creek (S-133)	14,442	14,170	2,065	5,705	7,168	22,392	43,819	15,680
S-135	8,347	12,601	369	7,666	7,323	27,192	58,525	17,432
Nubbin Slough (S-191)	210,695	155,419	63,178	176,204	132,339	167,181	170,085	153,586
WPB Canal (HGS-5) 3/	0	41,211	6,918	15,342	0	0	0	9,067
St. Lucie C (S-308) 3/	0	0	0	0	0	0	9,172	1,310
Caloosahatchee R (S-77) 3/	0	11,177	0	0	0	0	0	1,597
Rainfall	1,206,250	1,472,190	1,207,499	1,315,416	1,304,892	1,507,918	1,438,583	1,350,393
Total inflow	3,220,252	4,176,904	2,824,883	3,299,670	2,647,930	4,151,277	4,033,791	3,479,244
Outflows:								
N.N.R. & Hills. C (HGS-4)	276,173	322,241	220,498	186,146	169,284	257,238	197,737	232,760
Miami C (HGS-3)	161,255	275,431	158,424	84,465	79,277	144,482	128,614	147,421
S-4 1/	-	0	0	0	0	0	1,537	256
WPB Canal (HGS-5)	151,230	231,443	114,843	104,523	62,550	92,526	87,520	120,662
St. Lucie C (S-308)	10,632	245,351	10,893	9,537	50,367	236,693	283,411	120,983
Caloosahatchee R (S-77)	74,863	766,522	115,910	73,881	135,475	772,698	779,329	388,383
Seepage	52,000	52,000	52,000	52,000	52,000	52,000	52,000	52,000
Evaporation	2,120,264	2,082,860	2,183,982	2,140,336	1,890,285	2,036,168	1,965,673	2,059,930
Total outflow	2,846,417	3,975,848	2,856,550	2,650,888	2,439,805	3,591,238	3,495,821	3,122,367
Total inflow	3,220,252	4,176,904	2,824,883	3,299,670	2,647,930	4,151,277	4,033,791	3,479,244
Total outflow	2,846,417	3,975,848	2,856,550	2,650,888	2,439,805	3,591,238	3,495,821	3,122,367
Change in storage	-51,900	105,000	-98,400	602,200	400,100	356,900	146,300	208,671
Other sinks	425,235	96,056	66,733	46,582	-191,408	202,572	391,670	148,206

1/ 6 yr average only (thus, total input and total output ≠ Σ inputs and outputs, respectively)
2/ Annual 12 month period April 1st to March 31st
3/ Occasional inflows

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TABLE 6-2. PERCENTAGE ERRORS IN WATER BUDGET (Federico et al., 1981).

Year[1]	Avg. Annual storage (acre-feet)	Water Budget error (acre-feet)	% error[2]
1973	3,365,000	425,235	+12.6 [3]
1974	3,504,000	96,056	+ 2.7
1975	3,185,000	66,733	+ 2.1
1976	3,462,000	46,582	+ 1.3
1977	3,389,000	-191,408	- 5.6
1978	4,429,000	202,572	+ 4.6
1979	4,495,000	391,670	+ 8.7
Avg. 1973-79	3,690,000	148,206	+4.0

[1] Annual period is from April through March.

[2] Percentage error = ((Other sinks) + (Average annual storage)) x 100

[3] Positive error means that total inflows > total outflows.

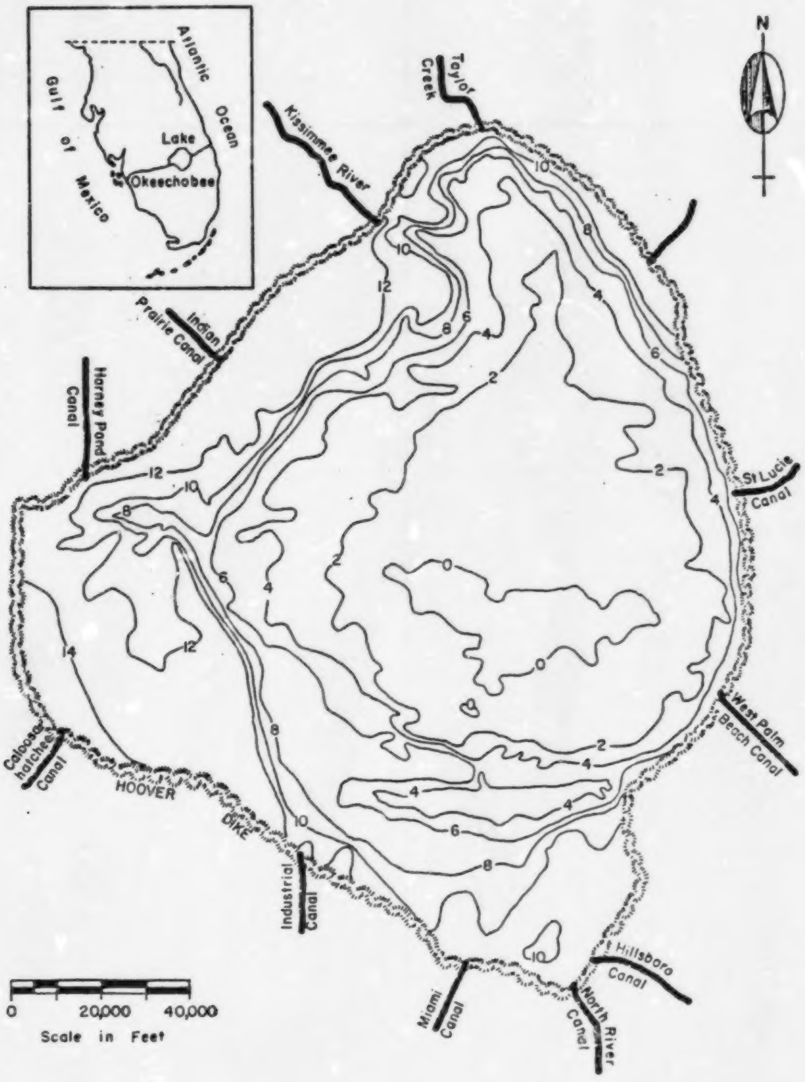
Atlantic Ocean
Gulf of Mexico
Lake Okeechobee
N
Taylor Creek
Kissimmee River
Indian Prairie Canal
Harney Pond Canal
Caloosahatchee Canal
HOOVER DIKE
Industrial Canal
Miami Canal
North River Canal
Hillsboro Canal
West Palm Beach Canal
St Lucie Canal
0
2
4
6
8
10
12
14
0 20,000 40,000
Scale in Feet

Figure 6-4. Bathymetric chart of Lake Okeechobee (after Gayle, 1975, and Brooks, 1974). Contour lines are marked in feet above mean sea level.

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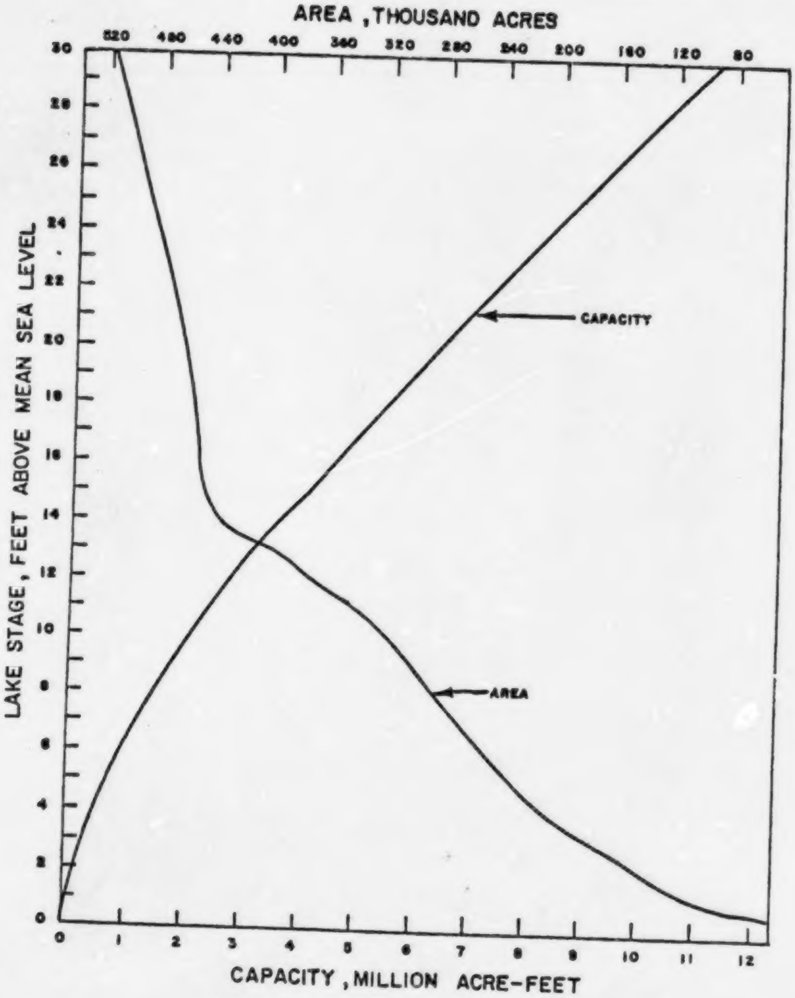

Figure 6-5. Stage, area, volume relationship for Lake Okeechobee (after Gayle, 1975, based on Corps of Engineers data).

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TABLE 6-3. HYDRAULIC AND MORPHOMETRIC PARAMETERS OF LAKE OKEECHOBEE (after Federico et al., 1981).

Year[1]	Mean Lake Stage (ft)	Mean[2] Depth $\bar{z}$, m	Surface Area A, km^2	Volume V, A-F	Water Residence Time τ, yrs	Hydraulic[4] Loading Rate q_s, m/yr
1973	13.58	2.46	1685	3,365,000	4.63	1.47
1974	13.86	2.54	1703	3,504,000	1.85	1.96
1975	13.16	2.40	1637	3,185,000	4.74	1.22
1976	13.81	2.48	1719	3,462,000	6.78	1.42
1977	13.65	2.47	1690	3,389,000	6.17	0.98
1978	16.01	2.99	1828	4,429,000	2.85	1.78
1979	16.15	3.03	1828	4,495,000	2.95	1.75
Average						
1973-79	14.32	2.64	1727	3,690,000	3.47	1.52

[1] Annual period is from April through March

[2] Mean depth = volume/surface area

[3] Based on surface outflows (excluding evaporation)

[4] Based on surface inflows (excluding rainfall)

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from which the water budget was calculated are given in Section 6-3-5. Climatological data for Florida are also published by NOAA.

6-3-5 Data Sources

The techniques for sampling all the data used in the water budget would occupy more space than is appropriate to this report. However, the period of record and the agency responsible for data collection are given in Table 6-4 for each of the water budget components. The techniques used to produce the data could be sought from the appropriate agencies.

6-4. LAKE QUALITY DESCRIPTION

6-4-1 Major Pollution Sources

Point Sources--

The point sources of pollution and nutrient loadings are the inflows described in Section 6-3-2. They are shown in Figure 6-2 and listed in Table 6-4. The inflow points were sampled biweekly throughout the study period. The water quality data from this sampling program are available on tape, and the means and ranges of the inflow water quality parameters are given in Table 6-5. It should be noted that inflow concentrations of many of the parameters depend partly on the flow rate. Consequently, the mean concentration with respect to time is not the same as the flow weighted average concentration. If a material budget is to be calculated using the annual average flows, it is necessary to calculate the flow weighted average inflow concentrations.

Precipitation--

Rainfall is a major source of water and nutrients to Lake Okeechobee, being responsible for an estimated 16.7% of the total phosphorus and 24.3% of the total nitrogen supplied to the lake during the study period. The quality of rainfall for Lake Okeechobee was derived from samples collected at three bulk precipitation collectors situated near the City of Lake Okeechobee, at the S-2 pump station, and at the S-131 inflow point. Samples were collected from the collectors daily. More information on the quality of rainwater in Florida may be obtained from the report by Brezonik et al. (1983a).

6-4-2 Biochemical Data

Mean Data Values--

The mean values of water quality parameters in Lake Okeechobee were calculated from samples collected at a network of eight stations in the limnetic zone. The station positions and the sampling program are described in Section 6-4-3. The samples were collected within one half meter of the surface at monthly intervals. The mean annual parameter values are given in Table 6-6, and the variations of selected mean values during the study period are shown in Figures 6-6 to Figure 6-12.

Derived Parameters--

The mean daily nitrogen to phosphorus mass ratios in the limnetic zone of Lake Okeechobee during the study period are shown in Figure 6-13.

TABLE 6-4. DATA SOURCES FOR WATER BUDGET[1] (after Federico et al., 1981).

Station	Inflow/Outflow	Period of Record	Source of Data
N.N.R. & Hills.C. (S-2)	inflow/outflow	4/73-1/80	USGS
		2/80-3/80	SFWMD[2]
Miami C. (S-3)	inflow/outflow	4/73-1/80	USGS
		2/80-3/80	SFWMD[2]
S-4	inflow/outflow[3]	6/74-3/80	SFWMD
Harney Pond C. (S-71)	inflow	4/73-1/80	USGS
		2/80-3/80	SFWMD (calc)[4]
Indian Prairie C. (S-72)	inflow	4/73-1/80	USGS
		2/80-3/80	SFWMD (calc)[4]
Kissimmee R. (S-65E)	inflow	4/73-3/80	USGS
S-84	inflow	4/73-1/80	USGS
		2/80-3/80	SFWMD (calc)[4]
Fisheating Creek	inflow	4/73-3/80	USGS
S-127	inflow	4/73-3/80	SFWMD
S-129	inflow	4/73-3/80	SFWMD
S-131	inflow	4/73-3/80	SFWMD
Taylor Creek (S-133)	inflow	4/73-3/80	SFWMD
S-135	inflow	4/73-3/80	SFWMD
Nubbin Slough (S-191)	inflow	4/73-3/80	SFWMD
WPB Canal (HGS-5)	inflow/outflow	4/73-1/80	SFWMD
		2/80-3/80	SFWMD (calc)[4]
St. Lucie Canal (S-308)	inflow/outflow	4/73-7/78	SFWMD (calc)[6]
		8/78-3/80	SFWMD (calc)[5]
Caloosahatchee R. (S-77)	inflow/outflow	4/73-1/80	USGS
		2/80-3/80	SFWMD[5]
Seepage	outflow	4/73-3/80	Shaw, SFWMD[7]
Rainfall	inflow	4/73-1/80	COE
		2/80-3/80	SFWMD (calc)[8]
Evaporation	outflow	4/73-1/80	COE
		2/80-3/80	SFWMD (calc)[9]

(continued)

TABLE 6-4 (concluded)

Station	Inflow/Outflow	Period of Record	Source of Data
Storage		4/73-1/80	COE
		2/80-3/80	SFWMD (calc)[10]
Surface Area		4/73-1/80	COE
		2/80-3/80	SFWMD (calc)[10]

[1] Stored on SFWMD tape #7083

[2] Preliminary SFWMD pumping records, including siphoning from Lake Okeechobee at S-2 and S-4 for 1/80-3/80

[3] Only outflow is siphoning from lake for 1/80-3/80

[4] Calculated from SFWMD operational logs and structure rating curves

[5] Preliminary COE data from SFWMD Field Services daily logs

[6] Calculated from a rainfall-runoff relationship for the St. Lucie Canal Basin by SFWMD Water Resources Division

[7] From: Shaw (1980).

[8] Calculated from preliminary COE data for seven rainfall stations using polygon method to weight stations, and using a 20% reduction for the lake as proposed by Riebson, Woodley, and Davis (1974).

Average L.O. rainfall = 0.8 (0.12 (HGS-6) + 0.19 (Indian Prairie) + 0.12 (HGS-1) + 0.21 (HGS-2) + 0.08 (HGS-4) + 0.11 (HGS-5) + 0.17 (Port Mayaca))

[9] Calculated from preliminary COE data using the COE weighing system:

Average L.O. evaporation = 0.434 ((HGS-6) + (HGS-2))

[10] Stage is calculated from preliminary COE data using a simple average:

Average L.O. stage = 1/3 ((HGS-6) + (HGS-2) + (Port Mayaca))

Storage and surface area are found from the stage-storage and stage-surface area relationships used by the COE.

Note: HGS-6, etc. refer to stations shown on Figure 6-2.

TABLE 6-5. MEAN VALUES AND RANGES OF LAKE OKEECHOBEE INFLOW WATER QUALITY PARAMETERS (Federico et al., 1981).

Inflow	Inorg N mg/l	Total N mg/l	Ortho P mg/l	Total P mg/l
S-2	1.28* 0.01-12.43**	4.01 1.03-18.20	0.059 0.002-0.396	0.149 0.021-0.832
S-3	1.01 0.01-7.60	3.33 0.81-13.07	0.032 0.001-0.880	0.070 0.005-1.120
S-4	0.57 0.01-2.95	2.78 0.65-5.58	0.149 0.002-1.247	0.210 0.019-1.412
Fisheating Ck	0.9 0.01-0.95	1.76 0.23-6.36	0.089 0.002-1.079	0.141 0.026-1.280
S-127	0.27 0.01-3.56	2.25 0.81-6.92	0.205 0.003-0.518	0.298 0.067-0.762
S-129	0.12 0.01-0.78	1.99 0.21-3.67	0.091 0.002-0.268	0.155 0.048-0.338
S-131	0.14 0.01-0.92	1.77 0.22-4.10	0.056 0.002-0.176	0.106 0.022-1.000
S-133	0.28 0.01-1.35	1.86 0.99-3.54	0.233 0.012-0.780	0.306 0.006-0.880
S-135	0.17 0.01-0.69	1.72 0.10-3.17	0.073 0.002-0.304	0.134 0.002-1.105
S-71	0.43 0.01-3.74	2.04 0.35-5.20	0.127 0.002-0.618	0.186 0.045-0.772
S-72	0.32 0.01-2.57	2.02 0.59-7.40	0.108 0.002-0.580	0.168 0.018-0.688
S-65E	0.18 0.01-0.49	1.43 0.27-4.41	0.050 0.002-0.267	0.086 0.025-0.490
S-84	0.20 0.01-0.74	1.39 0.18-2.99	0.027 0.002-0.188	0.064 0.005-0.910
S-191	0.69 0.01-2.21	2.27 0.77-5.52	0.756 0.002-1.513	0.905 0.010-2.108

* Mean value April 1973-March 1980

** Range

(continued)

TABLE 6-5 (continued)

Inflow	SO_4 mg/1	Cl mg/1	Alkalinity meq/1	Total Fe mg/1	TOC mg/1	Total Sus. Solid mg/1
S-2	101.3 46.1-251.9	136.1 15.7-403.6	5.04 .24-10.0	0.17 .02-.80	28.8 7.8-55.9	11.4 .7-56.
S-3	77.5 190.0-129.1	113.4 62.8-277.2	4.05 .4-8.4	0.16 .02-.78	23.0 11.4-44.8	12.7 .7-95.1
S-4	67.7 23.4-131.5	114.6 53.0-196.7	4.02 1.82-6.96	0.16 .02-.55	24.5 6.9-40.9	8.3 .8-35.7
Fisheating Ck	15.0 4.4-56.6	47.9 9.6-155.1	0.65 .07-4.22	0.41 .08-1.21	21.7 12.3-39.6	6.4 .3-66.0
S-127	65.6 35.2-109.6	88.0 28.7-207.9	2.70 .60-4.22	0.31 .02-1.07	24.4 14.8-31.4	6.4 1.0-16.0
S-129	7.13 53.1-80.2	72.1 17.6-109.1	2.44 1.39-4.22	0.27 .04-.96	24.3 16.1-47.6	6.3 1.0-14.0
S-131	34.0 13.5-54.0	80.2 34.7-116.6	2.35 .30-4.22	0.26 .02-.90	19.4 12.4-35.1	5.8 1.0-24.0
S-133	55.8 43.0-69.1	75.2 18.4-123.6	2.09 .87-4.22	0.31 .02-1.35	19.2 10.6-29.8	5.9 1.0-17.0
S-135	52.9 46.7-62.1	111.5 82.9-170.7	3.45 1.78-5.44	0.18 .02-.66	21.8 12.0-38.6	5.6 1.0-11.0
S-71	36.9 9.3-75.0	30.9 7.9-102.3	0.87 .10-4.22	0.50 .03-1.40	19.8 6.0-37.8	7.0 .2-37.9
S-72	58.9 20.4-125.2	33.4 1.8-113.7	0.99 .10-4.22	0.78 .10-2.60	24.5 7.0-39.5	6.4 .4-37.5
S-154	47.4 40.9-53.8	69.1 22.3-147.7	0.77 .43-1.12	0.70 .13-2.09	22.2 8.9-65.8	5.4 1.0-17.0
S-65E	21.1 8.5-40.0	19.7 4.0-67.0	0.60 .10-4.93	0.40 .18-.83	17.6 3.5-93.9	6.2 1.0-21.0
S-84	26.8 18.4-30.8	16.8 6.5-31.0	0.33 .08-4.22	0.72 .09-3.04	16.1 6.3-32.8	5.9 1.0-18.0
S-191	38.4 9.5-75.5	111.1 15.6-355.8	1.38 .34-4.22	0.48 .02-1.37	20.5 8.9-35.9	9.6 1.0-136.4

(continued)

TABLE 6-5 (continued)

Inflow	Turbidity JTU	Color Units	Temp °C	D.O. mg/l	Sp. Cond. µmhos/cm	pH
S-2	4.6	92	24.1	5.0	1025	7.67
	.9-25.	13-215	13.2-32.3	.3-9.8	297-1990	6.60-10.20
S-3	4.9	68	24.3	6.1	847	7.84
	.7-23.	6-161	10.8-32.2	2.1-10.3	320-1500	6.40-9.80
S-4	2.2	98	24.9	6.0	839	7.51
	.6-11.0	10-320	13.2-33.1	.4-13.8	360-1400	6.80-8.50
Fisheating Ck	1.1	211	24.6	5.5	251	6.67
	.4-3.5	28-344	11.1-34.0	.1-10.8	22-1250	5.10-9.40
S-127	1.5	172	24.8	5.3	787	7.68
	.05-3.6	85-320	14.1-32.0	.3-9.6	470-1310	6.75-8.84
S-129	1.4	136	24.7	5.8	677	7.88
	.5-3.7	70-250	14.3-31.9	.3-9.8	430-845	6.78-9.38
S-131	1.1	122	25.1	6.8	654	7.68
	.4-3.0	70-255	16.1-34.0	.4-11.0	220-820	6.08-8.40
S-133	2.6	111	23.4	5.4	664	7.64
	.6-17.0	60-220	13.5-29.9	1.7-9.6	480-860	6.91-8.40
S-135	2.4	80	24.1	5.8	920	7.97
	.7-8.7	35-170	14.0-32.0	1.6-9.8	698-1100	7.15-8.45
S-71	1.6	181	24.7	5.5	330	6.91
	.4-5.0	24-410	13.6-32.5	.3-9.6	75-2360	5.60-10.30
S-72	1.7	228	24.9	5.3	349	6.99
	.06-9.4	25-700	13.0-32.5	.3-10.0	97-1130	5.50-9.87
S-154	1.3	187	22.9	5.5	364	6.60
	.6-2.5	80-390	13.6-31.5	.8-9.0	162-734	6.10-7.30
S-65E	1.8	107	23.6	6.5	168	7.05
	.8-4.4	50-240	15.1-31.1	2.0-9.1	96-265	6.00-8.40
S-84	2.4	146	23.1	6.4	167	6.69
	0.8-20.0	80-318	15.4-29.4	2.3-9.1	70-246	5.70-8.40
S-191	3.7	204	24.2	4.7	603	7.06
	.5-49.0	26-400	13.3-31.9	.1-10.2	130-1300	5.70-8.51

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Inflow	SiO_2	Na	K	Ca	Mg	Hard
S-2	14.8 4.3-34.8	94.82 48.00-209.72	6.91 3.90-21.99	85.42 10.54-154.48	33.30 6.70-82.67	[illegible]50.3 91.6-628.1
S-3	12.4 3.7-24.9	75.00 33.90-130.00	5.78 4.00-12.19	75.10 22.31-143.92	25.41 6.50-47.50	[illegible]92.1 100.8-504.9
S-4	7.4 7.4-7.4	71.64 29.43-114.91	8.88 4.04-27.29	81.21 36.40-139.64	21.11 9.18-29.81	289.5 152.2-470.0
Fisheating Ck	3.6 0.1-14.1	26.98 4.31-99.00	2.75 0.20-9.80	14.58 3.09-51.00	6.20 1.15-22.40	61.8 13.1-219.5
S-127	6.7 1.9-11.4	47.21 33.00-93.15	4.39 1.65-6.55	52.93 33.80-100.17	10.88 6.30-22.40	176.8 122.3-326.4
S-129	6.8 1.6-10.8	40.42 20.00-64.02	4.57 2.40-6.33	56.04 17.00-80.69	10.10 7.60-17.40	181.9 87.7-263.7
S-131	4.1 .7-9.7	44.21 21.70-78.59	3.56 1.11-6.64	37.47 13.80-61.52	9.63 4.20-18.30	133.2 51.7-208.3
S-133	5.9 1.5-18.4	39.83 20.80-64.93	3.96 2.45-7.20	36.71 17.60-59.44	10.13 4.80-16.80	133.2 70.7-214.0
S-135	5.7 0.4-9.7	59.13 13.70-98.61	4.20 2.83-5.50	60.45 37.40-96.98	14.66 8.80-18.00	211.3 136.2-311.9
S-71	6.2 .5-14.1	20.18 3.08-99.00	3.16 1.52-8.80	29.46 7.80-62.83	7.88 2.40-22.40	106.0 33.5-219.5
S-72	7.5 1.7-22.3	20.77 1.30-99.00	3.03 1.17-9.68	30.44 4.40-222.00	8.03 1.80-22.40	109.1 18.4-579.9
S-154	0 ←	74.94 ——	6.19 —— One	28.61 Value ——	15.15 ——	133.8 →
S-65E	4.4 1.0-26.0	14.80 6.0-99.00	1.95 .90-8.80	15.34 5.40-108.00	4.44 2.20-22.40	56.6 22.5-283.7
S-84	3.7 0.4-14.1	12.62 6.00-99.00	1.99 1.20-8.80	13.29 4.50-51.20	4.86 2.50-22.40	53.2 24.2-219.5
S-191	6.5 0.5-48.0	61.94 7.00-151.20	7.66 2.17-13.46	35.56 7.00-74.47	11.72 2.80-25.00	137.0 29.0-276.1

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TABLE 6-6. SUMMARY OF MEAN ANNUAL LIMNETIC WATER QUALITY DATA (after Federico et al., 1981).

	Mean Annual Concentration							
Parameter*	1973	1974	1975	1976	1977	1978	1979	Avg. 1973-79
Ortho-P	0.005	0.014	0.013	0.016	0.013	0.019	0.045	0.018
Total P	0.049	0.049	0.058	0.055	0.063	0.067	0.097	0.063
Inorganic N	0.08	0.16	0.16	0.22	0.13	0.13	0.26	0.16
Organic N	1.55	1.29	1.44	1.81	1.53	1.63	1.74	1.57
Total N	1.63	1.45	1.60	2.01	1.64	1.77	2.02	1.73
Cond. (μmhos/cm)	574	570	594	621	617	614	545	589
Cl	85.6	79.1	87.4	90.5	98.0	91.8	83.0	87.4
Na	55.0	49.2	57.8	61.7	67.4	-	-	56.3
K	4.1	4.0	4.8	5.1	4.6	-	-	4.4
Ca	46.6	43.0	44.6	46.9	43.5	-	-	45.1
Mg	17.3	15.1	17.6	18.6	19.9	-	-	17.3
Hardness ($CaCO_3$)	187	169	184	194	190	-	-	184
SO_4	50.2	52.3	54.9	58.4	60.1	-	-	54.6
SiO_2	4.8	5.5	6.6	8.4	12.0	-	-	6.5
Alkalinity (meq/l)	2.7	2.5	2.6	2.7	2.5	2.3	1.9	2.5
Total Fe	0.22	0.47	0.52	0.56	0.22	0.26	0.53	0.44
Dissolved Oxygen	8.2	8.2	8.4	8.8	8.9	8.7	8.8	8.6
Turbidity (JTU)	11.7	19.8	26.6	25.7	15.5	9.1	13.9	18.0
Color (Pt units)	-	55	47	46	38	35	40	43
Secchi Disc (m)	0.6	0.6	0.5	0.6	0.7	-	-	0.6
Chlorophyll a (μg/l)	-	24.0	27.0	26.1	-	-	-	25.7

* Units in mg/l unless otherwise noted.

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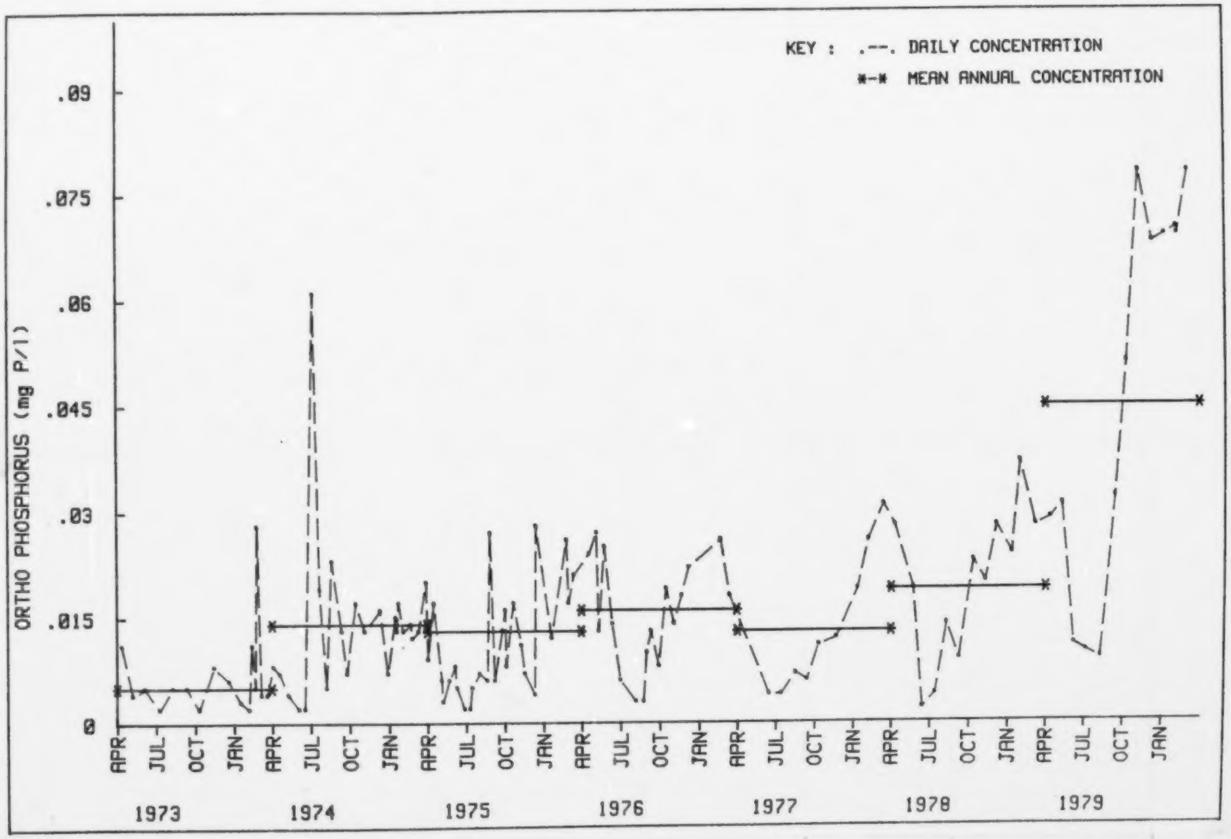

Figure 6-6. Daily and mean annual ortho-phosphorus concentrations in Lake Okeechobee (after Federico et al., 1981).

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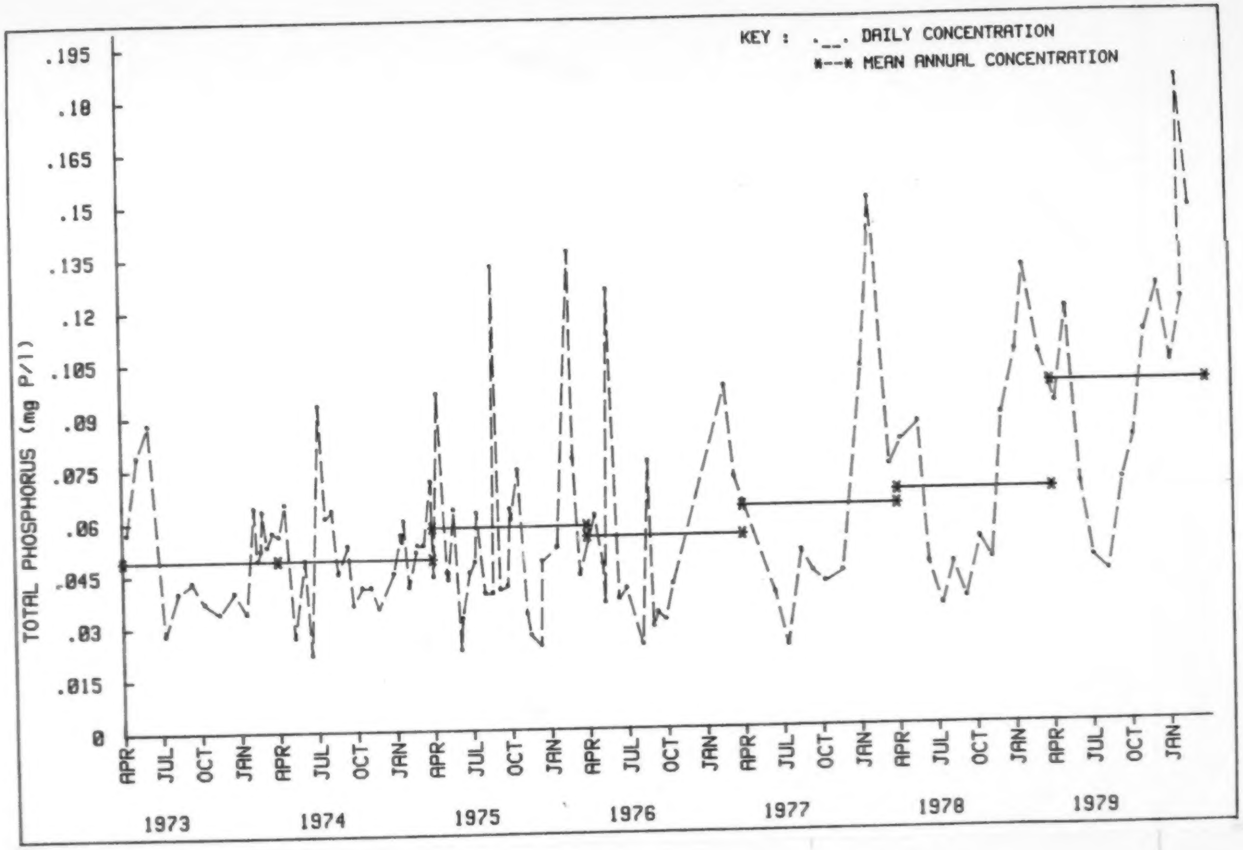

Figure 6-7. Daily and mean annual total phosphorus concentrations in Lake Okeechobee (after Federico et al., 1981).

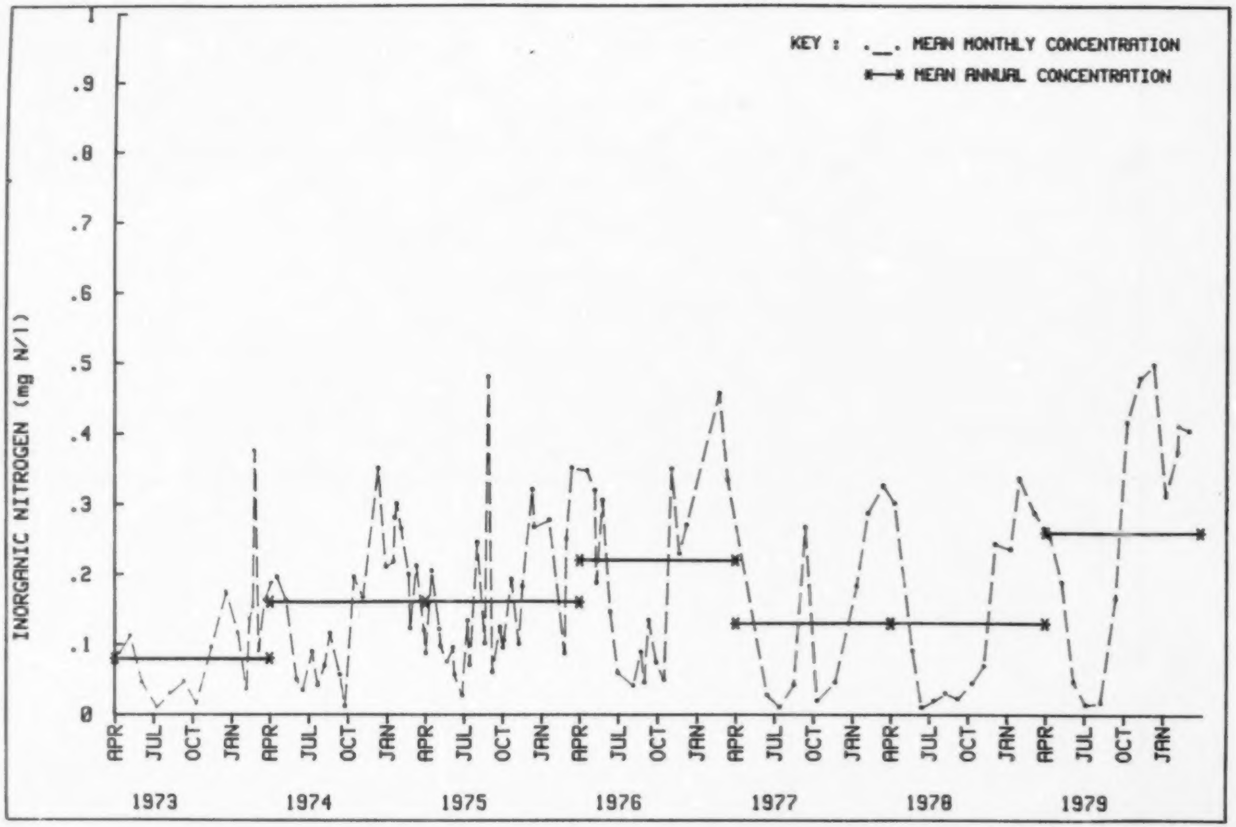

Figure 6-8. Mean monthly and mean annual inorganic nitrogen concentrations in Lake Okeechobee (after Federico et al., 1981).

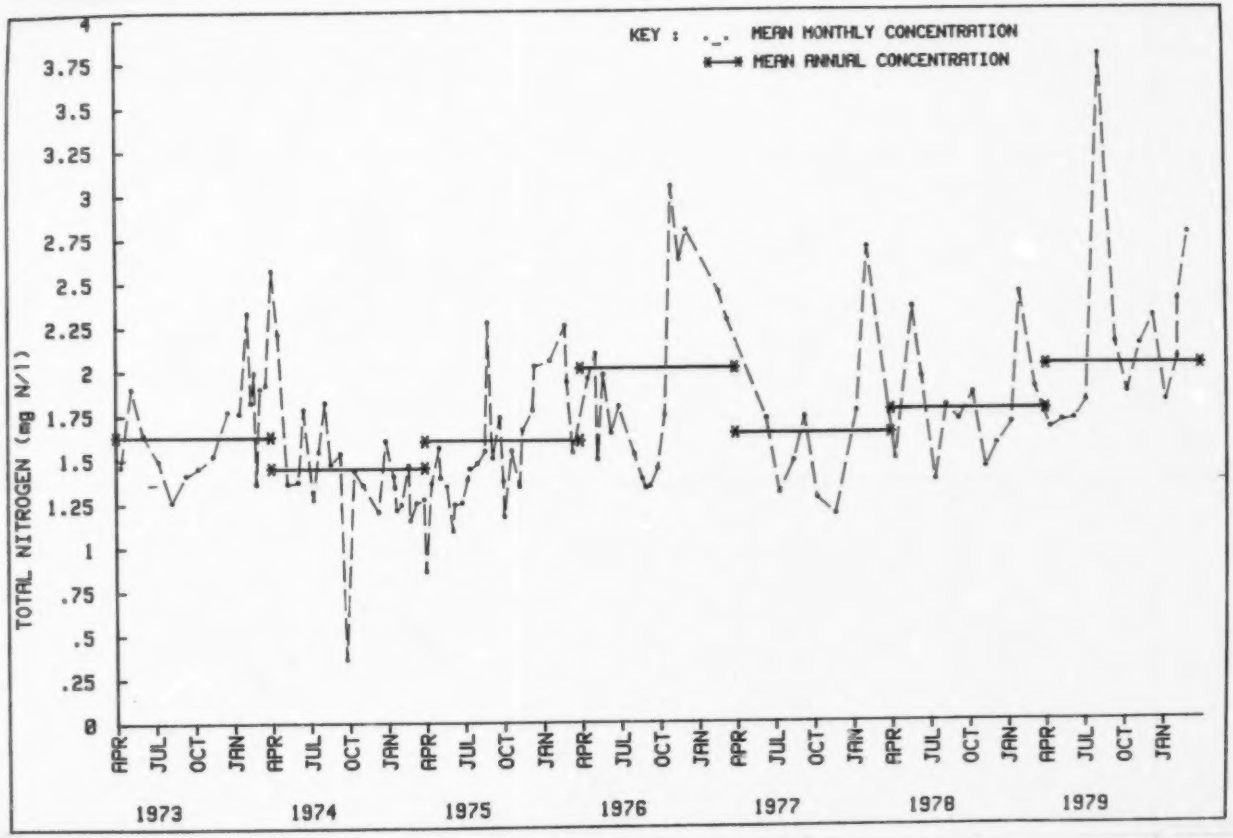

Figure 6-9. Mean monthly and mean annual total nitrogen concentrations in Lake Okeechobee (after Federico et al., 1981).

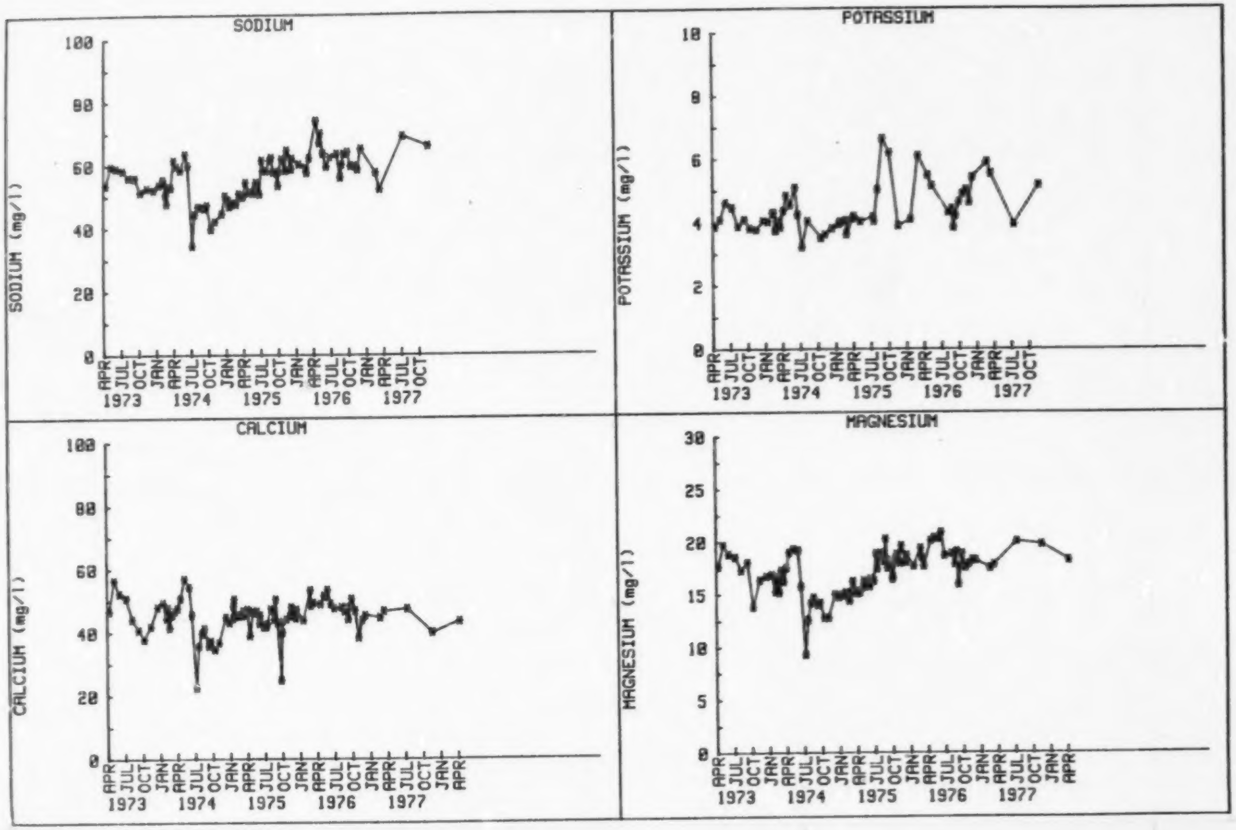

Figure 6-10. Mean daily major cation concentrations in Lake Okeechobee (after Federico et al., 1981).

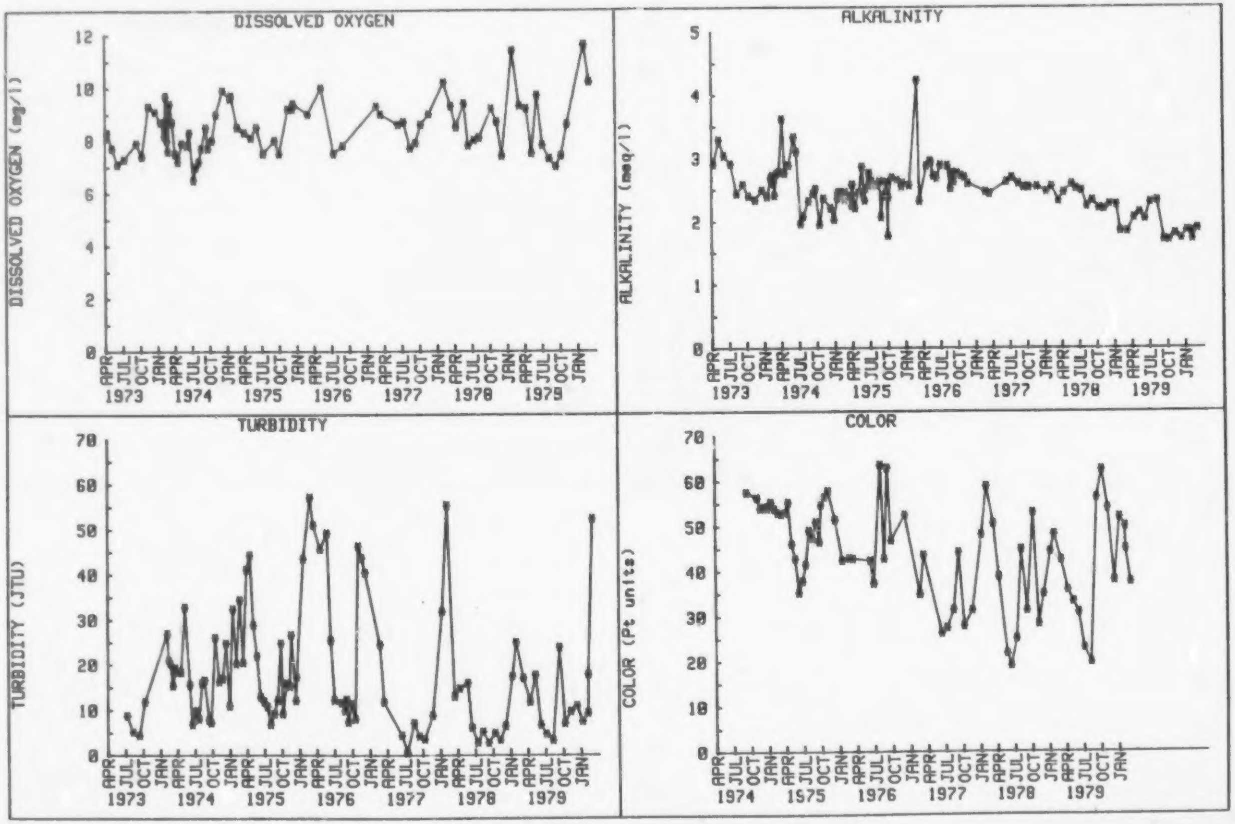

Figure 6-11. Mean daily dissolved oxygen, alkalinity, turbidity and color in Lake Okeechobee (after Federico et al., 1981).

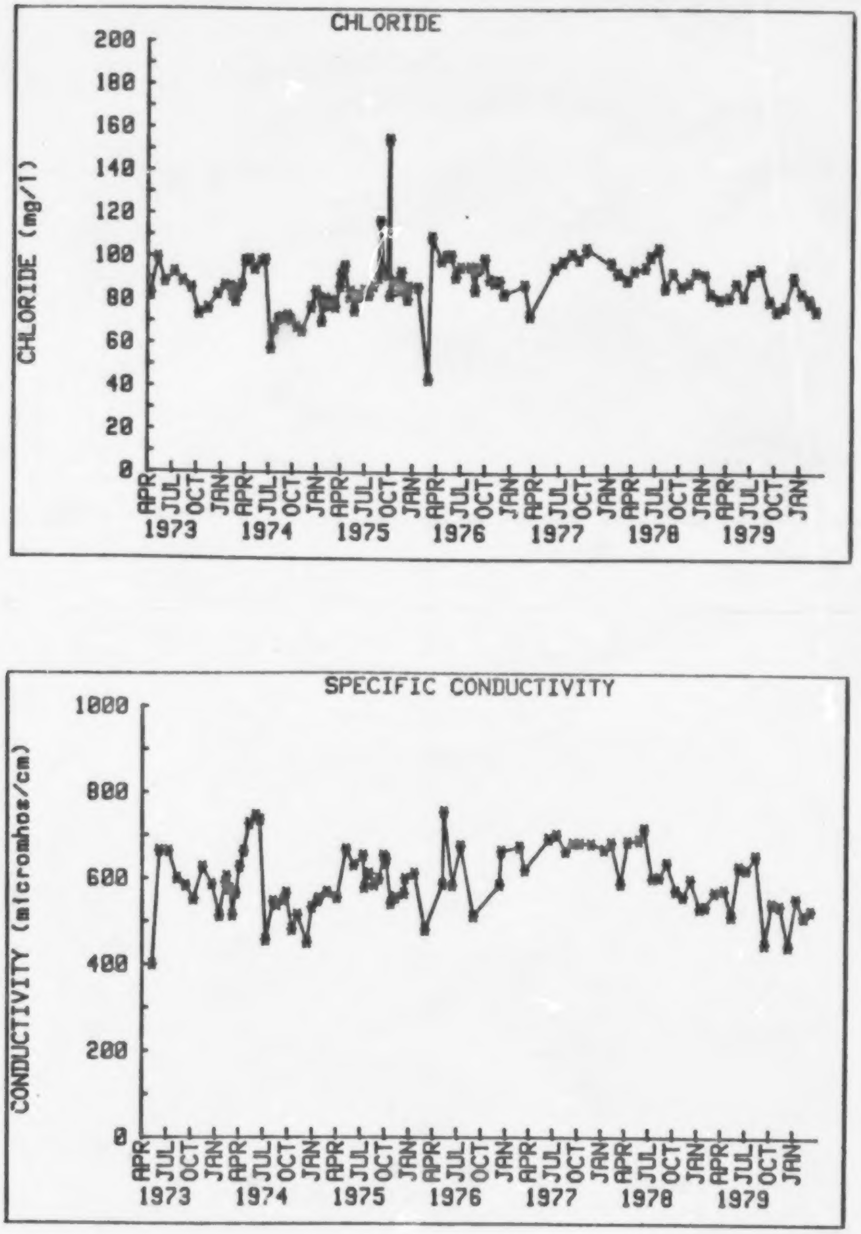

Figure 6-12. Mean daily chloride and conductivity in Lake Okeechobee (after Federico et al., 1981).

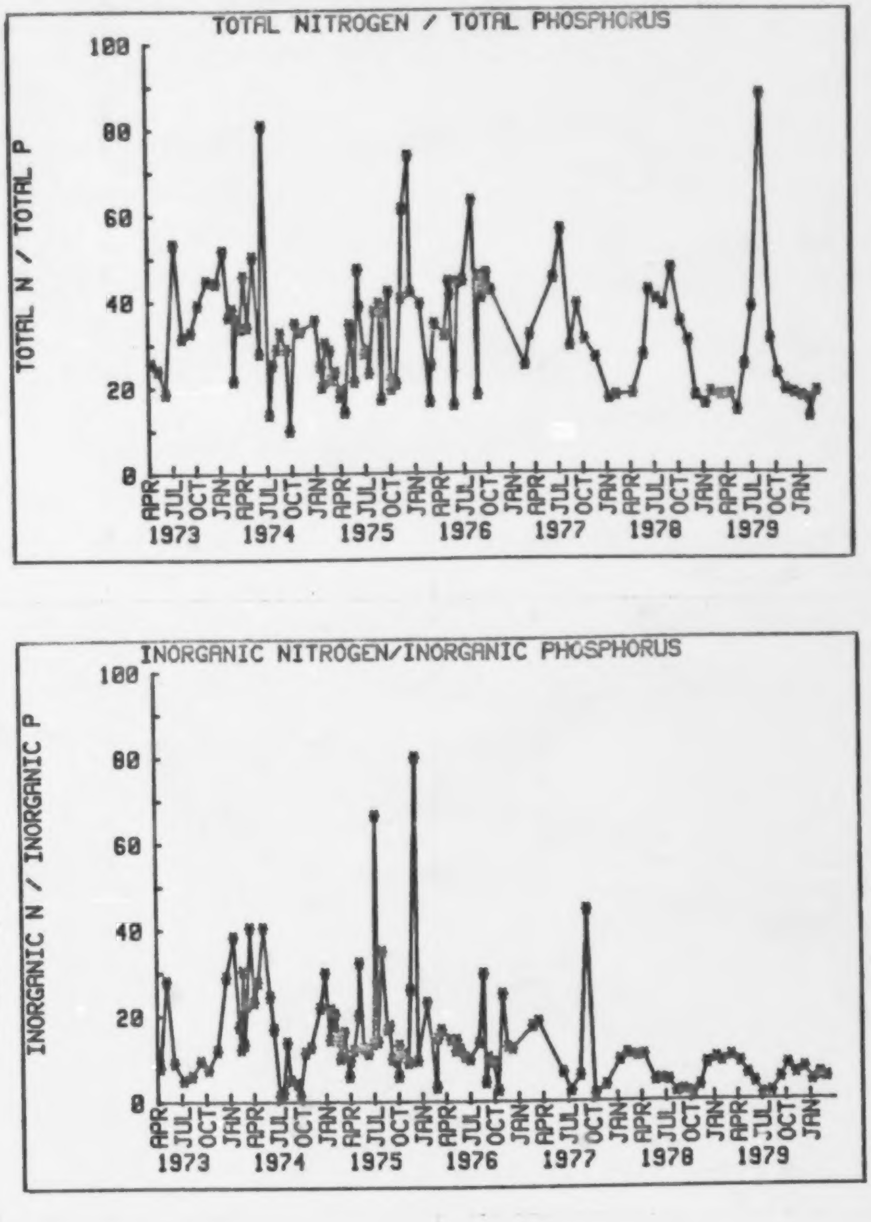

Figure 6-13. Mean daily nitrogen to phosphorus mass ratios in Lake Okeechobee (after Federico et al., 1981).

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The coefficient of phosphorus retention is calculated as:

$$R_{exp} = \frac{P_{in} + \Delta P - P_{out}}{P_{in} + \Delta P} \qquad (6\text{-}1)$$

where R_{exp} = coefficient of phosphorus retention,

P_{in} = mass of phosphorus imported to the lake,

ΔP = change in phosphorus storage, and

P_{out} = mass of phosphorus exported from the lake.

Similarly, the coefficient of nitrogen retention is calculated as:

$$R_{exn} = \frac{N_{in} + \Delta N - P_{out}}{N_{in} + \Delta N} \qquad (6\text{-}2)$$

The annual average coefficients of phosphorus and nitrogen retention are given in Table 6-7.

TABLE 6-7. ANNUAL AVERAGE COEFFICIENTS OF NUTRIENT RETENTION (Federico et al., 1981).

Year*	R_{exp}	R_{exn}
1973	0.895	0.757
1974	0.756	0.476
1975	0.842	0.717
1976	0.936	0.829
1977	0.916	0.785
1978	0.779	0.540
1979	0.813	0.494
Average 1973-79	0.840	0.643

* Represents 4/1/73-3/31/74, and so on for each year.

6-4-3 Measurement Listing

There were three distinct water quality sampling programs performed on Lake Okeechobee during the study period considered in this report. The programs are described separately below.

Inflow and Outflow Sampling--

The inflows and outflows were sampled throughout the seven years so that material budgets could be calculated for the lake. The positions of the inflows and outflows are given in Figure 6-2, and the parameters measured during the survey are given in Table 6-8. The frequency of sampling varied from weekly to monthly, but was mostly biweekly.

TABLE 6-8. SUMMARY OF WATER QUALITY SURVEYS (after Federico et al., 1981).

Survey	Inflows and Outflows		8 Station Limnetic Survey		40 Station Lake Survey	
	NO_x	Ortho-PO_4	NO_x	Ortho-PO_4	NO_x	Ortho-PO_4
	NO_2	Total-PO_4	NO_2	Total-PO_4	NO_2	Total-PO_4
	TKN	Alkalinity	NH_4	Alkalinity	NO_3	Alkalinity
	NH_4	Hardness	TKN	Color	NH_4	Total-Fe
	Cl	SiO_2	Cl	Turbidity	TKN	Total Organic Carbon
Parameters Measured	SO_4	Total Fe	Na	Chlorophyll-a†	Cl	Color
	Na	Total Organic Carbon	K			Turbidity
	K	Total Suspended Solids	Ca		*Dissolved Oxygen	
	Ca	Color	Mg		*Temperature	*pH
	Mg	Turbidity	*Dissolved Oxygen		*Conductivity	
	*Dissolved Oxygen		*Temperature	*pH		
	* Temperature	*pH	*Conductivity			
	*Conductivity					
Period of Record	April 1973 - March 1980		April 1973 - March 1980		May 1978 - Sept. 1979	
Frequency of Measurement	Mostly biweekly, also some weekly or monthly		Some biweekly, some monthly		Monthly	

† Chlorophyll-a measured April 1974 - March 1977.

* D.O., pH, Temperature, Specific Conductivity were all measured *in situ*.

TABLE 6-9. COORDINATES OF MONITORING STATIONS IN LAKE OKEECHOBEE (after Federico et al., 1981).

Station Code	Latitude	Longitude	Comments
LZ1*	27 12 20 N	80 47 47 W	
LZ2	27 11 30 N	80 49 52 W	P.W.S.**intake for Okeechobee City
LZ3	27 10 37 N	80 47 24 W	
LZ4	27 11 27 N	80 45 50 W	
LZ5	27 09 32 N	80 43 14 W	
LZ6	27 08 24 N	80 44 41 W	
LZ7	27 08 31 N	80 50 57 W	
LZ8	27 08 23 N	80 49 06 W	
LZ9	27 08 38 N	80 47 07 W	Also = Station L001*
LZ10	27 05 07 N	80 39 55 W	
LZ11	27 05 10 N	80 41 50 W	
LZ12	27 04 30 N	80 46 10 W	Also = Station L002
LZ13	27 02 55 N	80 43 47 W	Also = Station L003
LZ14	26 59 06 N	80 37 30 W	
LZ15	26 59 06 N	80 39 26 W	
LZ16	26 58 55 N	80 43 43 W	Also = Station L004
LZ17	26 51 52 N	80 38 02 W	
LZ18	26 52 53 N	80 39 36 W	
LZ19	26 49 37 N	80 40 07 W	P.W.S. intake for Pahokee
LZ20	26 50 48 N	80 41 18 W	
LZ21	26 48 05 N	80 43 07 W	
LZ22	26 46 54 N	80 41 53 W	
LZ23	26 42 07 N	80 42 58 W	
LZ24	26 44 04 N	80 43 59 W	P.W.S. intake for Belle Glade
LZ25	26 44 20 N	80 45 00 W	
LZ26	26 40 59 N	80 43 53 W	P.W.S. intake for South Bay
LZ27	26 41 54 N	80 48 23 W	
LZ28	26 46 30 N	80 47 33 W	Also = Station L007

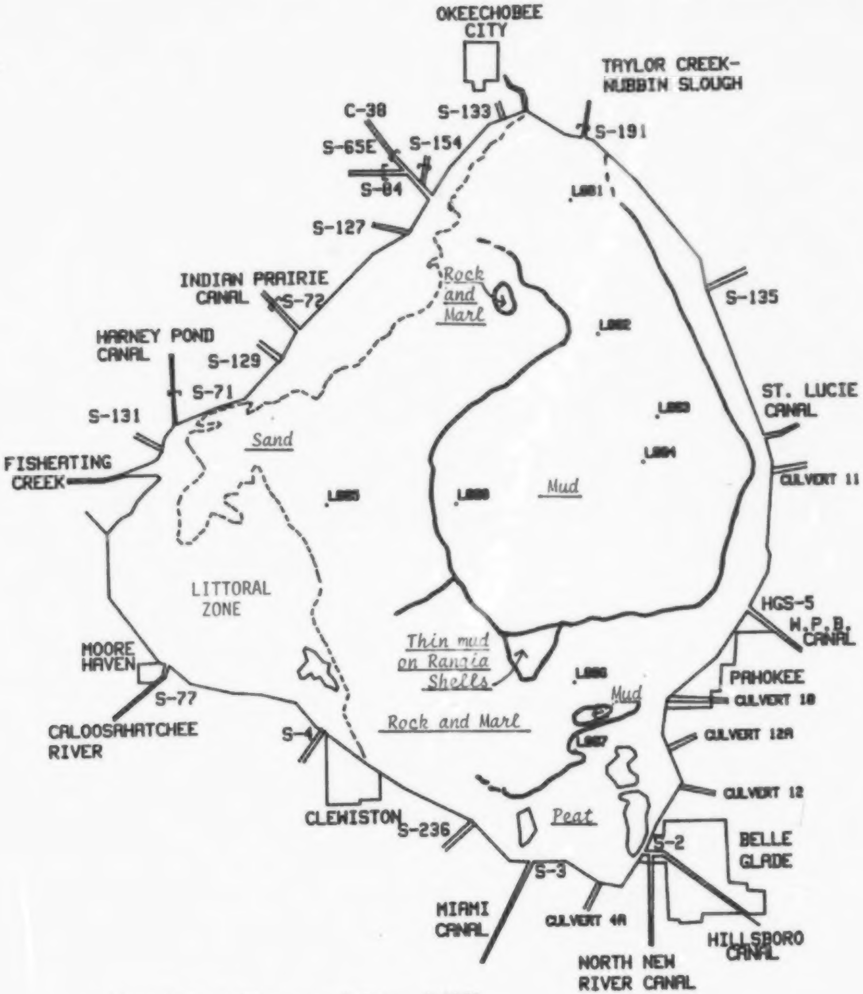
(continued)

TABLE 6-9 (concluded)

Station Code	Latitude	Longitude	Comments
LZ29	26 49 24 N	80 47 16 W	Also = Station L006
LZ30	26 47 54 N	80 51 38 W	P.W.S. intake for Clewiston
LZ31	26 45 35 N	80 55 05 W	
LZ32	26 47 27 N	80 57 42 W	
LZ33	26 53 27 N	80 52 57 W	
LZ34	26 57 33 N	80 54 14 W	Also = Station L008
LZ35	26 57 33 N	80 58 40 W	Also = Station L005
LZ36	26 58 42 N	81 02 12 W	
LZ37	26 58 07 N	81 04 05 W	
LZ38	27 02 00 N	80 56 10 W	
LZ39	27 00 56 N	80 54 42 W	
LZ40	26 52 56 N	80 47 15 W	

* Station codes LZ1 to LZ40 are from the 40 station lake survey, and Station codes L001 to L008 are from the 8 station limnetic survey.

** Public Water Supply.


OKEECHOBEE CITY
TAYLOR CREEK-NUBBIN SLOUGH
C-38
S-133
S-191
S-65E
S-154
S-84
L001
S-127
Rock and Marl
INDIAN PRAIRIE CANAL
S-72
S-135
L002
HARNEY POND CANAL
S-129
S-71
ST. LUCIE CANAL
L003
S-131
Sand
L004
FISHEATING CREEK
CULVERT 11
L005
L008
Mud
LITTORAL ZONE
HGS-5
W.P.B. CANAL
MOORE HAVEN
Thin mud on Rangia Shells
L006
PAHOKEE
S-77
Mud
CULVERT 10
CALOOSAHATCHEE RIVER
S-4
Rock and Marl
L007
CULVERT 12A
CULVERT 12
CLEWISTON
S-236
Peat
S-2
BELLE GLADE
S-3
MIAMI CANAL
CULVERT 4A
HILLSBORO CANAL
NORTH NEW RIVER CANAL

Adapted from Gleason and Stone (1975)

Figure 6-14. Lake Okeechobee limnetic water quality stations (after Federico et al., 1981).

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8 Station Limnetic Survey--

The limnetic survey was performed throughout the seven years considered here. It was based on data from eight stations in the limnetic zone whose positions had been chosen to give good indications of the average water quality in the limnetic zone. The positions of the stations were chosen where the lake was well mixed vertically and where the water quality would not be unduly influenced by nearby inflows. The parameters measured at the limnetic stations are given in Table 6-8, and their positions are shown in Figure 6-14. The coordinates of the stations are given in Table 6-9.

40 Station Lake Survey--

The forty station survey was carried out between May 1978 and September 1979, with samples taken at monthly intervals. The station positions were chosen so that spatial water quality variations in the lake and the spatial influence of inflows could be investigated. The parameters measured in the survey are given in Table 6-8, and the station coordinates are given in Table 6-9. The positions of the stations are shown in Figure 6-15.

6-4-4 Sampling Techniques

The information on sampling techniques was abstracted directly from the report on Lake Okeechobee water quality studies by Federico et al. (1981) and is summarized in Table 6-10.

Sampling and Analytical Methods--

Water samples were collected at a depth of 0.5 meters using a 2.2 liter PVC Niskin sampler. Those samples collected for dissolved nutrients and anion analysis, (ortho-PO_4, NO_x, and NO_4, and NO_2, SO_4, Cl^-, alkalinity and color) were filtered immediately upon collection through a 0.45 micron Nucleopore$^{(R)}$ membrane filter. Aliquots for cation analysis (Ca^{++}, Mg^{++}, K^+, Na^+) were also filtered and acidified with concentrated nitric acid (2 drops/60 ml). Unfiltered aliquots were collected for TKN, total PO_4, total Fe, TOC, total suspended solids, and turbidity. All samples were stored in polyethylene bottles, on ice in the dark, until they were transported back to the laboratory. In the laboratory the samples were kept at 4°C in the dark. Analyses were commenced within one week of sample collection.

The analytical methods used in this study are described in Table 6-10 and were either recommended or approved by the Environmental Protection Agency (1974) or the American Public Health Association (1975).

In situ dissolved oxygen, temperature, specific conductivity, and pH measurements were made using a Hydrolab Surveyor II$^{(R)}$ or a Hydrolab Series 8000$^{(R)}$. Secchi disc readings were measured in centimeters using a

For purposes of this report, inorganic nitrogen was calculated from the sum of NO_2, NO_4, and NH_4. Inorganic phosphorus is synonymous with ortho phosphorus. The values for nitrogen and phosphorus analyses are reported as mg/l N and mg/l P, respectively.

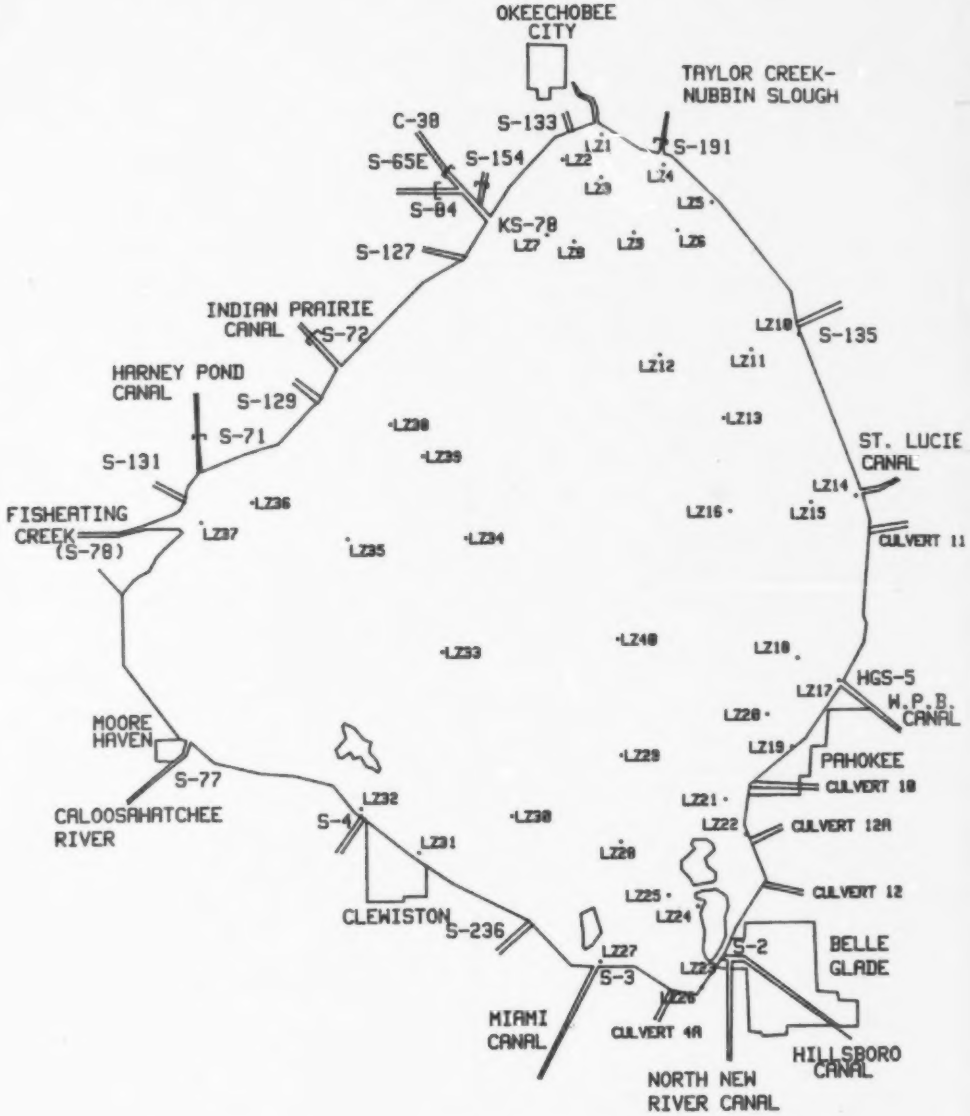
OKEECHOBEE CITY
TAYLOR CREEK-NUBBIN SLOUGH
C-38
S-133
S-65E
S-154
S-191
S-84
KS-78
S-127
LZ1
LZ2
LZ3
LZ4
LZ5
LZ6
LZ7
LZ8
LZ9
INDIAN PRAIRIE CANAL
S-72
LZ10
S-135
HARNEY POND CANAL
LZ11
LZ12
S-129
LZ13
S-71
LZ38
ST. LUCIE CANAL
S-131
LZ39
LZ14
LZ36
FISHEATING CREEK
(S-78)
LZ37
LZ16
LZ15
LZ35
LZ34
CULVERT 11
LZ33
LZ40
LZ18
HGS-5
LZ17
W.P.B. CANAL
MOORE HAVEN
LZ20
LZ19
PAHOKEE
S-77
LZ29
CULVERT 10
CALOOSAHATCHEE RIVER
LZ32
S-4
LZ30
LZ21
LZ22
CULVERT 12A
LZ31
LZ28
CLEWISTON
LZ25
CULVERT 12
S-236
LZ24
S-2
BELLE GLADE
LZ27
LZ23
S-3
LZ26
MIAMI CANAL
CULVERT 4A
HILLSBORO CANAL
NORTH NEW RIVER CANAL

Figure 6-15. Forty station location map (after Federico et al., 1981).

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TABLE 6-10. ANALYTICAL METHODOLOGIES (after Federico et al., 1981).

AutoAnalyzer II Method Determination	Method	Range	Sensitivity	Detection Limits
Alkalinity	Colorimetric Automated Methyl Orange, Technicon AA II Method #111-71W, modified EPA Method #310.2	0-5.0 meq/l	0.1 meq/l	0.1 meq/l
Ammonia	Colorimetric Automated Phenate, Technicon AA II Method #154-71W, modified EPA Method #350.1	0-0.50 mg/l	0.01 mg/l	0.01 mg/l
Chloride	Colorimetric Automated Ferricyanide, Technicon AA II Method #99-70W, modified EPA Method #325.2	0-200.0 mg/l	2.0 mg/l	4.0 mg/l
Nitrite	Colorimetric Automated Diazotization with Sulfanilamide and coupling with N-(1 naphthyl) ethylenediamine Dihydrochloride, Technicon colorimetric, automated AA II Method #120-70W, modified EPA Method #353.2	0-0.200 mg/l	0.002 mg/l	0.004 mg/l
Nitrate	Same as nitrite with Cadmium Reduction Column. Technicon AA II Method #100-70W, modified EPA Method #353.2	0-0.200 mg/l	0.002 mg/l	0.004 mg/l
Total Kjeldahl Nitrogen	Colorimetric, Semi-automated Block Digestor, Technicon AA II Method #376-75W, 334-74A, modified EPA Method #351.2	0-0.10 mg/l	0.001 mg/l	0.002 mg/l
Ortho Phosphate	Colorimetric, Automated, Phosphomolybdenum Blue Complex with Ascorbic Acid Reduction, Technicon AA II Method #155-71W, modified EPA Method #365.1	0-0.10 mg/l	0.001 mg/l	0.002 mg/l
Total Phosphate	Colorimetric, Semi-automated Persulfate Digestion followed by same method as Ortho Phosphate Technicon AA II Method #155-71W, modified EPA Method #365.1	0-0.10 mg/l	0.001 mg/l	0.002 mg/l

(continued)

TABLE 6-10 (continued)

AutoAnalyzer Method (continued)

Determination	Method	Range	Sensitivity	Detection Limits
Silicates	Colorimetric, Automated Ascorbic Acid Reduction of Silicomolybdate Complex, Technicon AA II Method #105-71W	0-20.0 mg/1	0.20 mg/1	0.40 mg/1
Sulfate	Colorimetric, Automated Methylthymol Blue, Technicon AA II Method #118-71W, modified EPA Method #375.2	0-250.0 mg/1	5.0 mg/1	5.0 mg/1
Total Dissolved Iron	Colorimetric, Automated TPTZ Complex with thioglycolic acid pretreatment, Technicon AA II Method #109-71W	0-1.0 mg/1	0.02 mg/1	0.02 mg/1
Total Iron	Colorimetric, Semi-automated, Hydrochloric Acid Digestion modified Standard Methods 13th Ed., pp. 192, 1971, followed by Total Dissolved Iron Determination	0-1.0 mg/1	0.02 mg/1	0.02 mg/1

Physical Parameters

Determination	Method	Range	Detection Range
Suspended Solids	Gravimetric Standard Methods Procedure #208D, 14th Ed., pp. 94, 1975, EPA Methods #160.1 to #160.4.	20-20,000 mg/1	1.0 mg/1 or 5%, whichever is greater
pH	Electrometric, EPA Method #150.1	0-14 pH	(sensitivity 0.01 pH)
Turbidity	Nephelometric Standard Methods #214A, 14th Ed., pp. 132, 1975, EPA Method #180.1	0-1,000 N.T.U.	2% of scale used
Color	Colorimetric, modified Standard Method #204A, 14th Ed., pp. 64, 1975 (modified as per N.C.A.S.I. Technical Bulletin #243) modified EPA Method #110.2	0-500 mg/1 as platinum in platinum-cobalt solution	1.0 mg/1

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TABLE 6-10 (concluded)

Atomic Absorption

Metals - Major Cation

Determination	Method	Range	Detection Range
Sodium	Atomic Absorption Direct Aspiration with Dual Capillary System (DCS), EPA Method #273.1	0-150 mg/1	As calculated from absorbance
Potassium	Atomic Absorption Direct Aspiration with Dual Capillary System (DCS), EPA Method #258.1	0-10 mg/1	As calculated from absorbance
Calcium	Atomic Absorption Direct Aspiration with Dual Capillary System (DCS), Samples are treated with LA_2O_3/HCl with DCS, EPA Method #215.1	0-150 mg/1	As calculated from absorbance
Magnesium	Atomic Absorption Direct Aspiration with Dual Capillary System (DCS), Same Treatment as calcium, EPA Method #242.1	0-40 mg/1	As calculated from absorbance

Chlorophyll Analysis--

Chlorophyll a samples were collected for 3 years, from April 1974 to March 1977. Unfiltered samples for chlorophyll analysis were placed in 1000 ml polyethylene bottles and stored in the dark, on ice, until transported back to the laboratory (maximum time 24 hours). Immediately upon return to the laboratory, the samples were filtered through Gelman glass fiber filters (0.45 micron pore size) and neutralized with $MgCO_3$. If necessary the samples were frozen for not more than one week before continuing the analysis. The filters were ground for one to two minutes with a plastic pestle and and extracted with 90% acetone for approximately 18 hours. The extracted samples were then analyzed on a Coleman double beam spectrophotometer using the trichromatic method of Strickland and Parsons (1972).

Rainwater Quality Collection--

The quality of rainfall in the vicinity of Lake Okeechobee was measured by using three bulk precipitation collectors located near the City of Okeechobee, at the S-2 pump station, and at S-131 (Figure 6-2). The rainwater collection aparatus consisted of a 20 cm funnel covered by a screen (1 mm mesh). The collection vessel was a 1 liter bottle. A crown was placed around the edge of the screen in order to reduce perching and subsequent contamination by bird droppings. All the collection equipment was constructed of a plastic, except for the housing, which was constructed of wood. The collector was mounted 1 m above ground level, in the open, in order to prevent ground splash and drip contamination. The rainwater collector was serviced daily during week days. Daily samples (if any) were frozen into biweekly composites.

Annual Periods--

Throughout this report year designations will represent the 12 month period from April 1st of the year indicated through March 31st of the following year (i.e., 1973 corresponds to the period April 1, 1973 to March 31, 1974).

6-5. COMPUTER DATA SET

The data indicated in Table 6-8 are included on the computer data set. Monthly inflows and outflows, total phosphorus loads and ortho-phosphorus loads for the locations shown on Figure 6-2 are also included. Detailed rainfall and pan evaporation data must be obtained from the NWS "Climatological Data for Florida."

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SECTION 7

LAKE JACKSON

7-1. INTRODUCTION

Lake Jackson is situated in Northwest Florida, just north of Tallahassee. The lake has an area of 16.2 km^2 (6.25 mi^2) at 87 feet MSL, and its watershed occupies 111.9 km^2 (43.20 mi^2). The only inputs into the lake are runoff and rainfall, and the only water losses are through evaporation and groundwater recharge. Because the lake has no permanent inflows or outflows, its level has a history of wide fluctuations in response to rainfall and evaporation. The wide fluctuations in response to climatic conditions are complicated further by the formation of sinkholes. During periods when the water table is drawn down excessively, there is a tendency for sinkholes to open in the bottom of the lake so that the level is lowered suddenly and dramatically. This phenomenon has an interesting 25 year cycle, with Lake Jackson sinkholes being recorded in 1907, 1932, 1957 and 1982.

Historically, Lake Jackson has had good water quality and has been valued for its sport fishing. However, by the early 1970's urban development had spread outward from Tallahassee so that some of the southern parts of the lake's watershed had become urbanized. Although the northern areas of the lake generally retain good water quality, water quality in the southern parts of the lake, especially Meginniss Arm, is degraded by urban runoff.

The data presented here cover the period of July 1971 through June 1981. Most of the data are derived from four water quality studies on the lake, and additional hydrologic and climatic data are presented.

7-2. SOURCE LITERATURE

The water quality data presented with this report were drawn from studies by Harriss and Turner (1974), Babcock and Rousseau (1976), Mason and Belanger (1978), and Burnett and Donahue (1982). The study by Harriss and Turner was performed under a cooperative agreement between Florida Game and Fresh Water Fish Commission and Florida State University. In this study water quality samples were taken at monthly intervals from 14 lake stations during the period July 1971 through June 1974. The study also included water quality sampling of storm water runoff in the Meginniss Arm and Ox Bottom Creek watersheds. Turner personal communication, 1983) has also supplied additional storm runoff quality data which he collected. These data have not been published, but there are quite a number of papers based on analyses of the data (Turner et al., 1975; Burton et al., 1976, 1977a, 1977b, 1978).

The study by Babcock and Rousseau (1976) was published by the Florida Game and Fresh Water Fish Commission as a follow-up to the information presented by Harriss and Turner (1974). The report presents information on fish populations, aquatic invertebrate populations, macrophyte distribution, and water quality in the lake. This report presents water quality data collected at quarterly intervals from 12 stations. Of the 12 stations, 11 are in the same positions as stations in the Harriss and Turner study.

The study by Mason and Belanger (1978) was performed under a contract between the Florida Institute of Technology and the Florida Department of Environmental Regulation (FDER). Water quality samples were taken at monthly intervals from December 1976 to November 1977 at 10 stations. Due to a series of problems, runoff from only one storm event was sampled during the study.

The most recent water quality study was performed by Burnett and Donahue of Florida State University under a grant from the USEPA to the FDER. The report includes water quality data taken at monthly intervals from 10 lake stations between December 1977 and June 1981, and some storm water quality data from stations in the Meginnis Arm watershed.

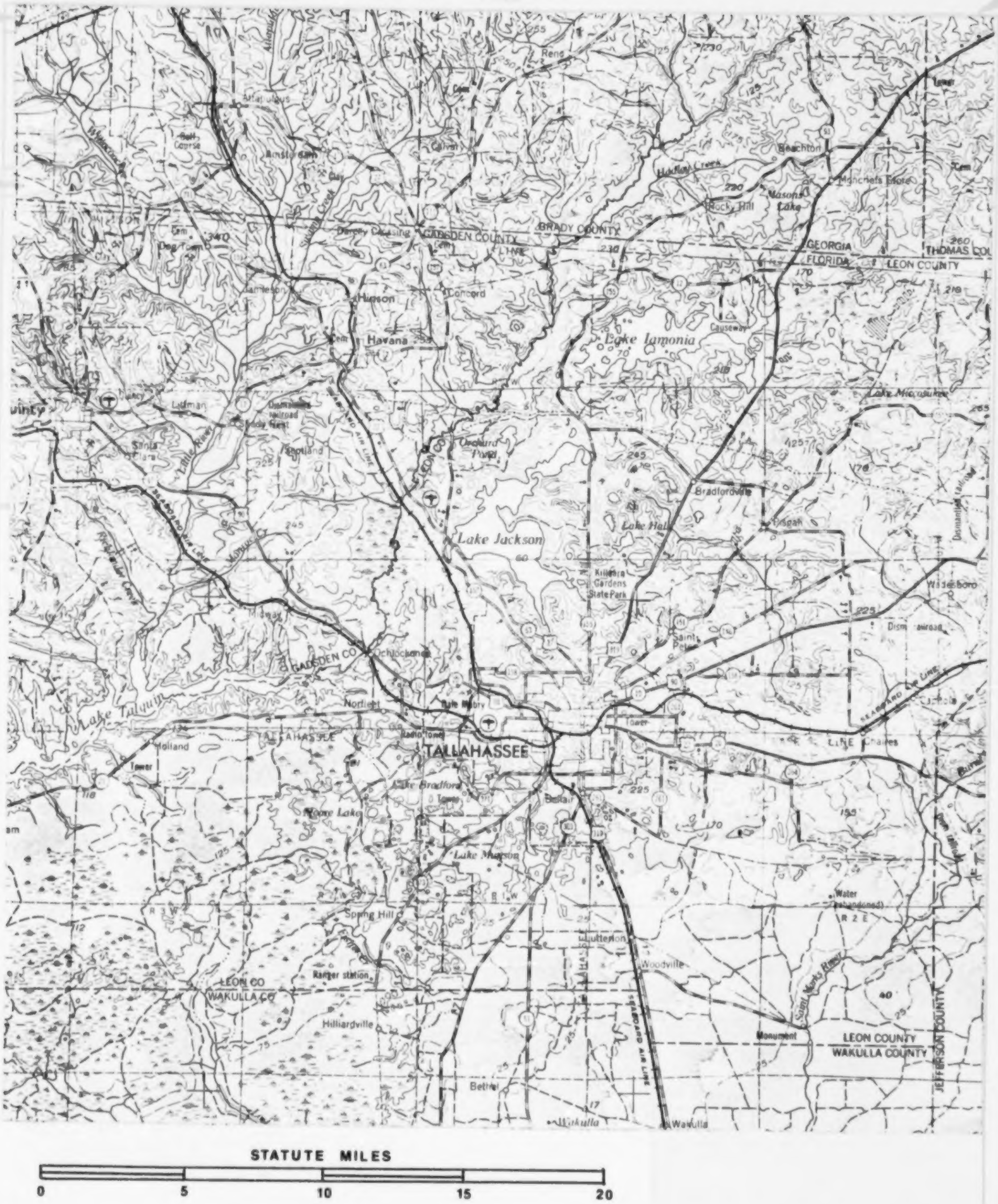
Additional hydrologic data collected by the USGS and climatic data assembled by the University of Florida are also presented.

7-3. WATERSHED DESCRIPTION

7-3-1. Study Area

Lake Jackson is situated in Northwest Florida just north of Tallahassee in Leon County. A general location map is given in Figure 7-1. The lake has an area of 16.2 km^2 (6.25 mi^2) at 87 feet MSL, and its stage fluctuates widely in response to rainfall and evaporation.

The lake's watershed is shown in Figure 7-2 and land uses in areas surrounding the lake are shown in Figure 7-3. Table 7-1 gives the key to the lake use codes shown in Figure 7-3. The watershed has an area of 111.9 km^2 (43.20 mi^2). The parts of the watershed surrounding the southern section of the lake are largely urbanized. Most of this urbanization took place in the late 1960's and early 1970's as the city of Tallahassee expanded northwards, and it has resulted in a marked degradation of water quality in the southern portion of the lake. The lowest water quality in the lake is usually found in the Meginniss Arm as a result of urban stormwater runoff which is channelled into the Meginniss Arm tributary. Recently an artificial marsh has been constructed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FLORIDA
GADSDEN COUNTY
GRADY COUNTY
THOMAS COUNTY
LEON COUNTY
Beachton
Mason Lake
Havana
Hinson
Concord
Lake Iamonia
Lake Miccosukee
Orchard Pond
Lake Jackson
Lake Hall
Bradfordville
Killearn Gardens State Park
Lake Talquin
Ochlockonee
Midway
TALLAHASSEE
Lake Bradford
Lake Munson
Bellair
Chaires
Capitola
Waddsboro
Spring Hill
Woodville
Ranger station
Hilliardville
LEON CO
WAKULLA CO
Monument
LEON COUNTY
WAKULLA COUNTY
JEFFERSON COUNTY
Bethel
Wakulla
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Figure 7-1. General location map of Lake Jackson (after USGS area map, 1960).

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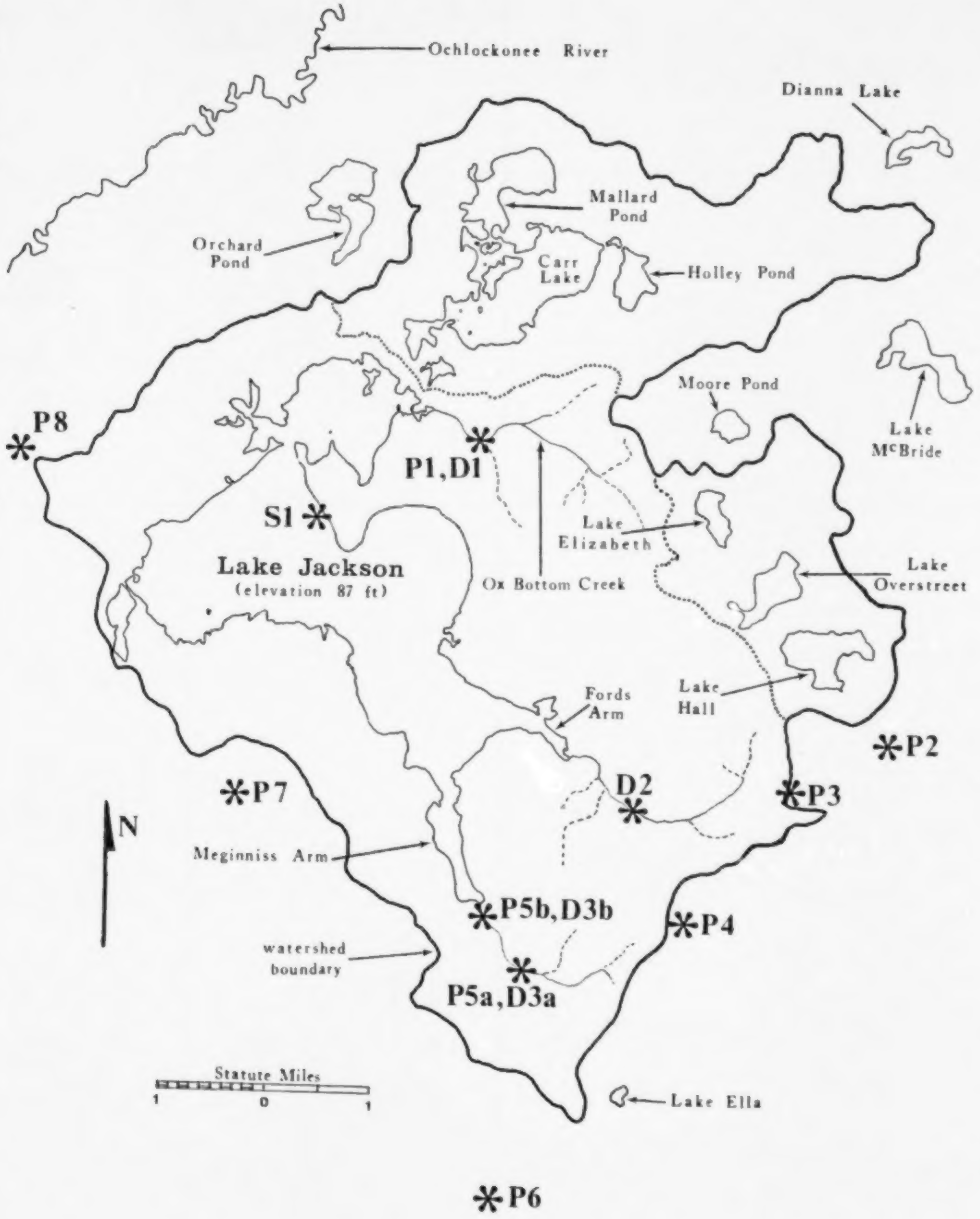
Ochlockonee River
Dianna Lake
Mallard Pond
Orchard Pond
Carr Lake
Holley Pond
Moore Pond
Lake McBride
P8
P1,D1
S1
Lake Jackson
(elevation 87 ft)
Ox Bottom Creek
Lake Elizabeth
Lake Overstreet
Lake Hall
Fords Arm
P2
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D2
P7
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Meginniss Arm
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P4
watershed boundary
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Lake Ella
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Figure 7-2. Watershed Map of Lake Jackson Showing Positions of Hydrologic Data Gaging Stations.

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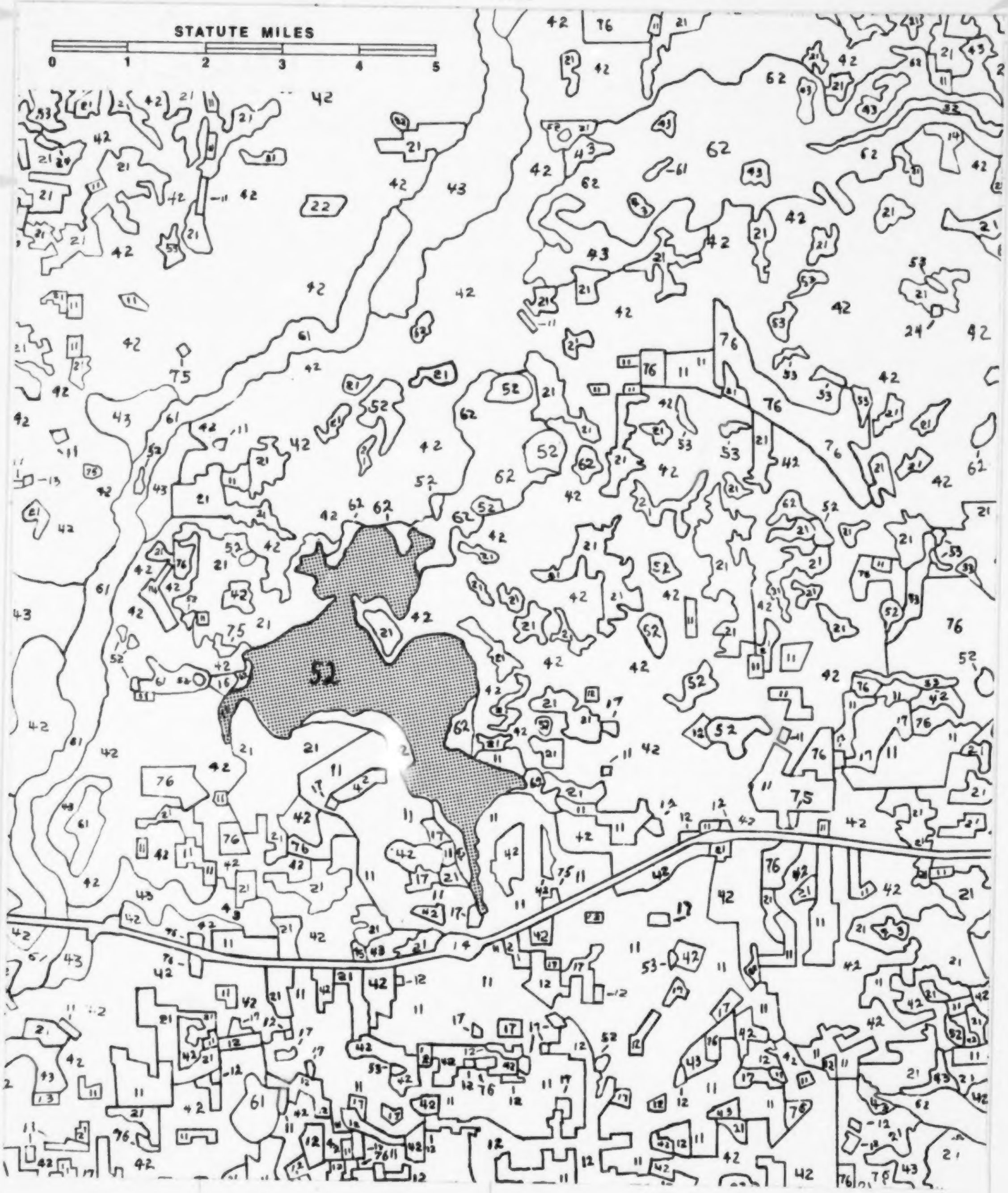

Figure 7-3. Land use in areas surrounding Lake Jackson (after USGS land use map, 1976). The map shows land use data collected in 1972 and 1973. Lake Jackson is shown shaded, and the key to the land use code numbers is given in Table 7-1.

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TABLE 7-1. KEY TO LAND USE CODES USED IN FIGURE 7-3 (after USGS, 1976)

General Land Use	Code Number	Detailed Land Use
Urban or Built-up Land	11	Residential
	12	Commercial & Services
	13	Industrial
	14	Transportation, Communications, & Utilities
	15	Industrial & Commercial Complexes
	16	Mixed Urban or Built-up Land
	17	Other Urban or Built-up Land
Agricultural Land	21	Cropland & Pasture
	22	Orchards, Groves, Vineyards, Nurseries & Ornamental Horticultural Areas
	23	Confined Feeding Operations
	24	Other Agricultural Land
Rangeland	31	Herbaceous Rangeland
	32	Shrub & Brush Rangeland
	33	Mixed Rangeland
Forest Land	41	Deciduous Forest Land
	42	Evergreen Forest Land
	43	Mixed Forest Land
Water	51	Streams & Canals
	52	Lakes
	53	Reservoirs
	54	Bays & Estuaries
Wetland	61	Forested Wetland
	62	Nonforested Wetland

(Continued)

TABLE 7-1. (Concluded)

General Land Use	Code Number	Detailed Land Use
Barren Land	71	Dry Salt Flats
	72	Beaches
	73	Sandy Areas Other Than Beaches
	74	Bare Exposed Rock
	75	Strip Mines, Quarries, & Gravel Pits
	76	Transitional Areas
	77	Mixed Barren Land

to filter some of the pollutant load out of waters flowing into the Meginniss Arm.

The USGS has calculated that the boundaries of the Lake Jackson are in the position shown by the solid line in Figure 7-2. Two sections of the watershed are separated from the lake by dotted lines because their contributions to the lake are uncertain. The northeast section of the watershed drains into Mallard Pond, Carr Lake and Holley Pond. These lakes are separated from Lake Jackson by a narrow strip of swampy land which bears a light duty road at an elevation of 90 feet. When the lake level rises above 90 feet, all these small lakes are directly connected to Lake Jackson. However, when the lake level drops below 90 feet the small lakes are separated from Lake Jackson, and it seems unlikely that much runoff from the outer watershed section reaches Lake Jackson. The eastern section of the watershed drains into Lake Elizabeth, Lake Overstreet and Lake Hall. If Lake Elizabeth or Lake Hall overflowed, they would overflow into Lake Overstret, but there do not appear to be any defined flow channels linking these lakes. There is a more clear-cut overflow channel from Lake Overstreet to Fords Arm, but this is almost always dry (personal communication, Hal Mattraw, USGS Tallahassee District Office, 1983).

7-3-2. Hydrologic Data

Point Inflows and Outflows--

Lake Jackson has no point outflows. The three principal point inflows to the lake are the Meginniss Arm tributary, Fords Arm tributary, and Ox Bottom Creek. These creeks are shown in Figure 7-2 and the positions of the USGS gages in the creeks are given in Table 7-2. The creeks carry runoff from subcatchments of the lake's watershed, and their flows are intermittent. However, the creeks were not gaged continuously during the ten years of lake quality data collection. The periods during which the flows in the creeks and other hydrologic parameters were measured are shown in Figure 7-4. The mean daily creek flows during the measurement periods are given in the computer data set.

Non-Point Inflows and Outflows--

Unfortunately, estimates of the lake's non-point inflows and outflows have not been made. The principal non-point inflow is probably runoff from those parts of the watershed which do not drain into the three creeks described above. There are a number of small, intermittent runoff streams distributed round the edge of the lake. After heavy rains, there is probably some seepage into the lake from the raised and saturated sections of the watershed. It is unlikely that the underlying semi-confined aquifer ever contributes water to the lake (personal communication, J.R. Wagner, Northwest Florida Water Management District, 1983).

Seepage is also a non-point outflow from the lake when the potentiometric surface of the surrounding phreatic aquifer drops below the lake level, and when water from the lake drains through the lake floor into the underlying aquifer. The other major non-point water loss from

** Daily precipitation values are available on paper from FSU Dept. of Meteorology. The computer data tape gives monthly summed values.

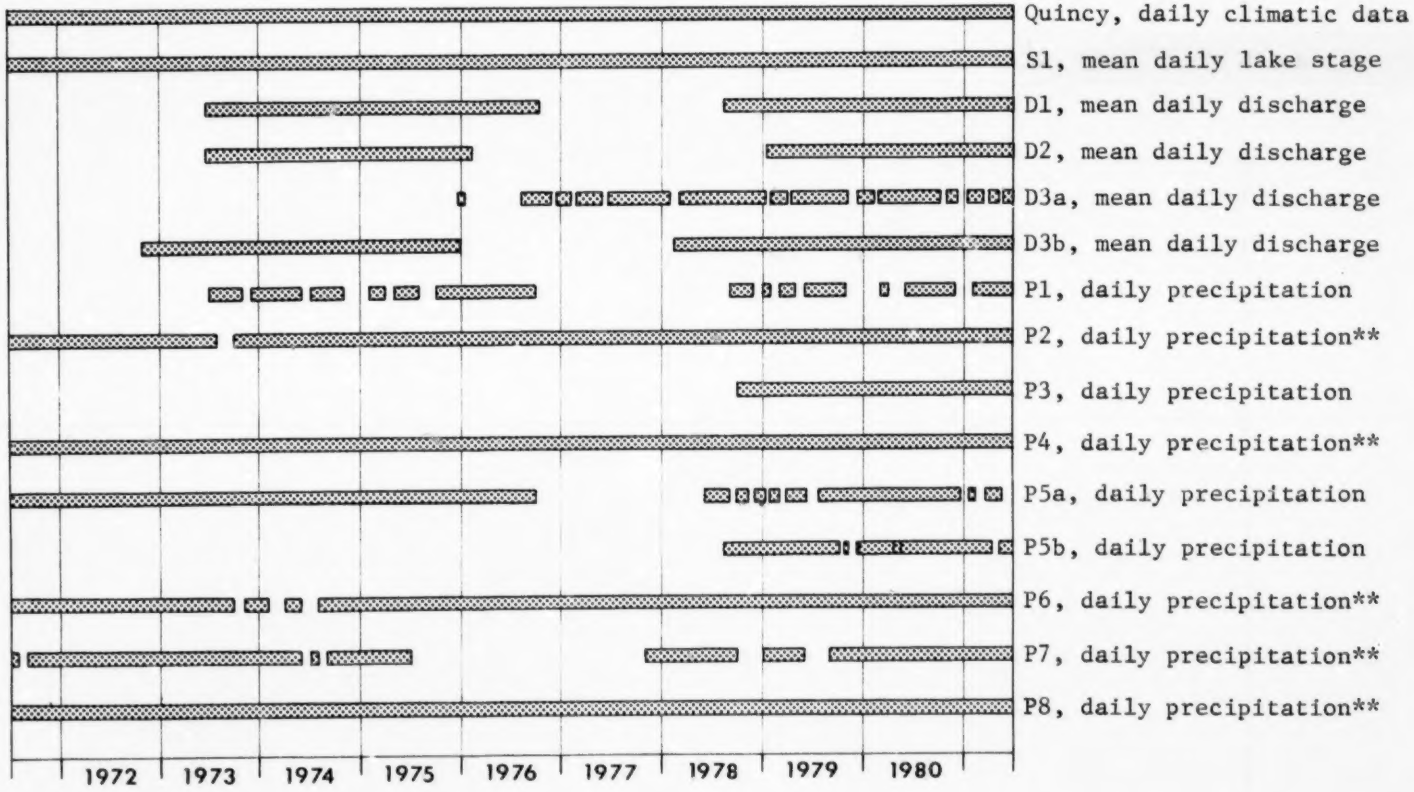

Figure 7-4. Duration of hydrologic data records for Lake Jackson.

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TABLE 7-2. POSITIONS AND TYPES OF HYDROLOGIC DATA GAGES.

Map ID Code*	Measuring Agency	Agency Station ID Number	Agency Station Name	Data Type	Station Latitude	Station Longitude
P1	USGS	02329104	Ox Bottom Creek	Daily Precipitation	30°33'02"N	84°18'15"W
P2	FSU	--	Killearn	Daily Precipitation**	30°30'32"N	84°14'17"W
P3	USGS	303010084151200	Rain Gage 13 at Timberlane Mall	Daily Precipitation	30°30'10"N	84°15'12"W
P4	FSU	--	Waverly	Daily Precipitation**	30°29'04"N	84°16'12"W
P5a	USGS	02329180	Meginniss Arm Tributary	Daily Precipitation	30°28'40"N	84°17'41"W
P5b	USGS	02329186	Meginniss Arm Tributary below I-10	Daily Precipitation	30°29'06"N	84°18'06"W
P6	FSU	--	FSU Campus	Daily Precipitation**	30°26'46"N	84°17'57"W
P7	FSU	--	Lake Jackson	Daily Precipitation**	30°30'03"N	84°20'28"W
P8	FSU	--	Commercial Airport	Daily Precipitation**	30°32'51"N	84°22'23"W
D1	USGS	02329104	Ox Bottom Creek	Mean Daily Discharge	30°33'02"N	84°18'15"W
D2	USGS	02329161	Fords Arm Tributary	Mean Daily Discharge	30°29'59"N	84°16'39"W
D3a	USGS	02329180	Meginniss Arm Tributary	Mean Daily Discharge	30°28'40"N	84°17'41"W
D3b	USGS	02329186	Meginniss Arm Tributary below I-10	Mean Daily Discharge	30°29'06"N	84°18'06"W
S1	USGS	02329200	Lake Jackson	Mean Daily Lake Stage	30°31'43"N	84°21'30"W

* Stations are shown in Fig. 7-2.

** Daily precipitation values are available on paper from FSU Dept. of Meteorology. The computer data tape gives monthly summed values.

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the lake is due to evaporation. Since evaporation at the lake was not measured, it must be estimated using an energy balance method or using measurements of pan evaporation at Quincy, 20 miles west of the lake.

Precipitation--

Precipitation was measured at four USGS gages and at five gages tended by the Florida State University (FSU) Department of Meteorology. These gages are shown in Figure 7-2, their positions are given in Table 7-2, and the periods of record are shown in Figure 7-4. The computer data set contains the entire record of daily precipitation at the USGS gages, and it should be noted that the precipitation values after 1981 are provisional. The computer data set also contains monthly preciptation values from the FSU gages. The daily precipitation values at these gages may be obtained on paper from Dr. Charles Jordan, Florida State University, Department of Meterology.

Lake Stage--

Lake stage was measured throughout the ten years during which water quality measurements were made. The position of the USGS stage recorder is given in Figure 7-2 and Table 7-2, and the mean daily values of lake stage are given in the computer data set. Mean monthly values of lake stage are shown in Figure 7-5.

Water Budget--

Unfortunately, a water budget has not yet been calculated for Lake Jackson. At the time of writing, the University of Florida is attempting to construct a water budget for the lake, based on the hydrologic data described above and on pan evaporation data from a station in Quincy. The climatological data measured at Quincy are described in Section 7-3-4.

7-3-3. Bathymetric Data

The report by Harriss and Turner (1974) presents a bathymetric map of Lake Jackson, which is shown in Figure 7-6, and a graph of lake surface area and lake volume as functions of lake surface elevation, which is shown in Figure 7-7.

7-3-4. Climatological Data

The town of Quincy is 15 miles west of Lake Jackson, and an extensive set of climatological data measurements has been assembled at the University of Florida. The parameters measured at Quincy are listed in Table 7-3 and the data from this station are presented in the computer data set.

7-3-5. Data Sources

The precipitation and discharge data from the Lake Jackson watershed were obtained from the USGS. The flow recorders and rain gages operate continuously and take readings every five minutes which are coded on a punched paper tape. The tapes are collected and decoded, and the five-minute values are temporarily stored in a computer memory bank.

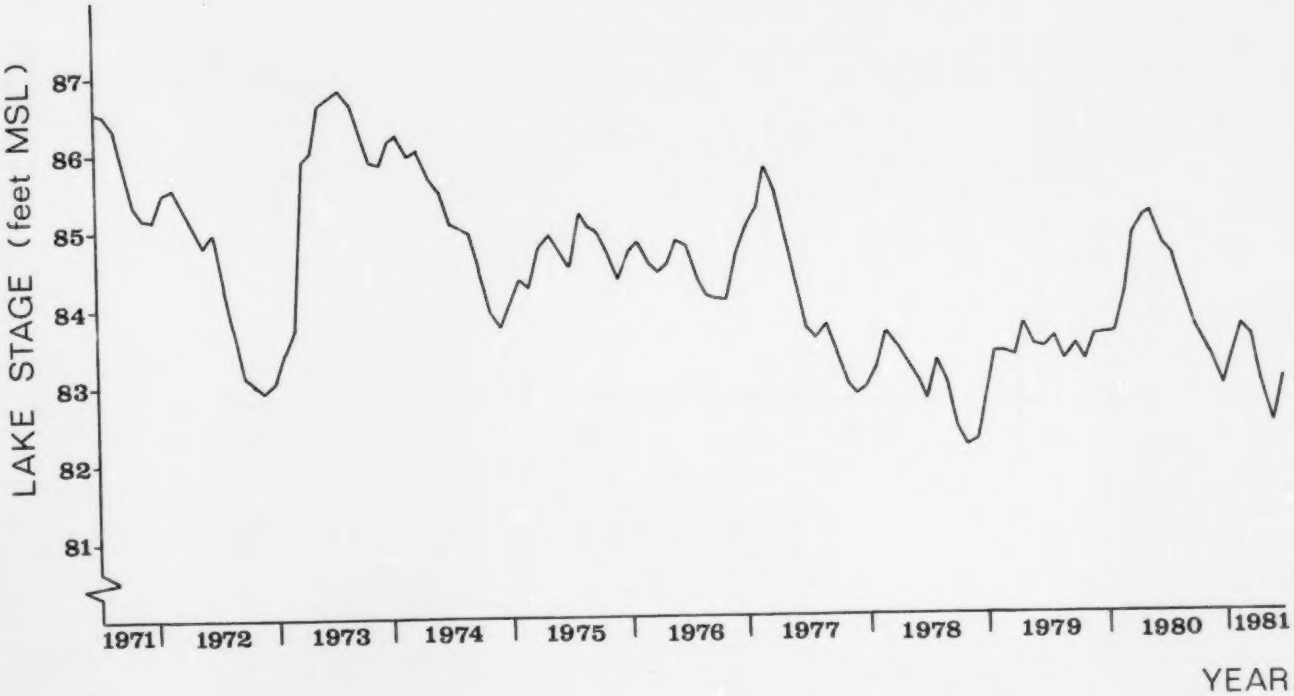

Figure 7-5. Lake Jackson mean monthly lake stages.

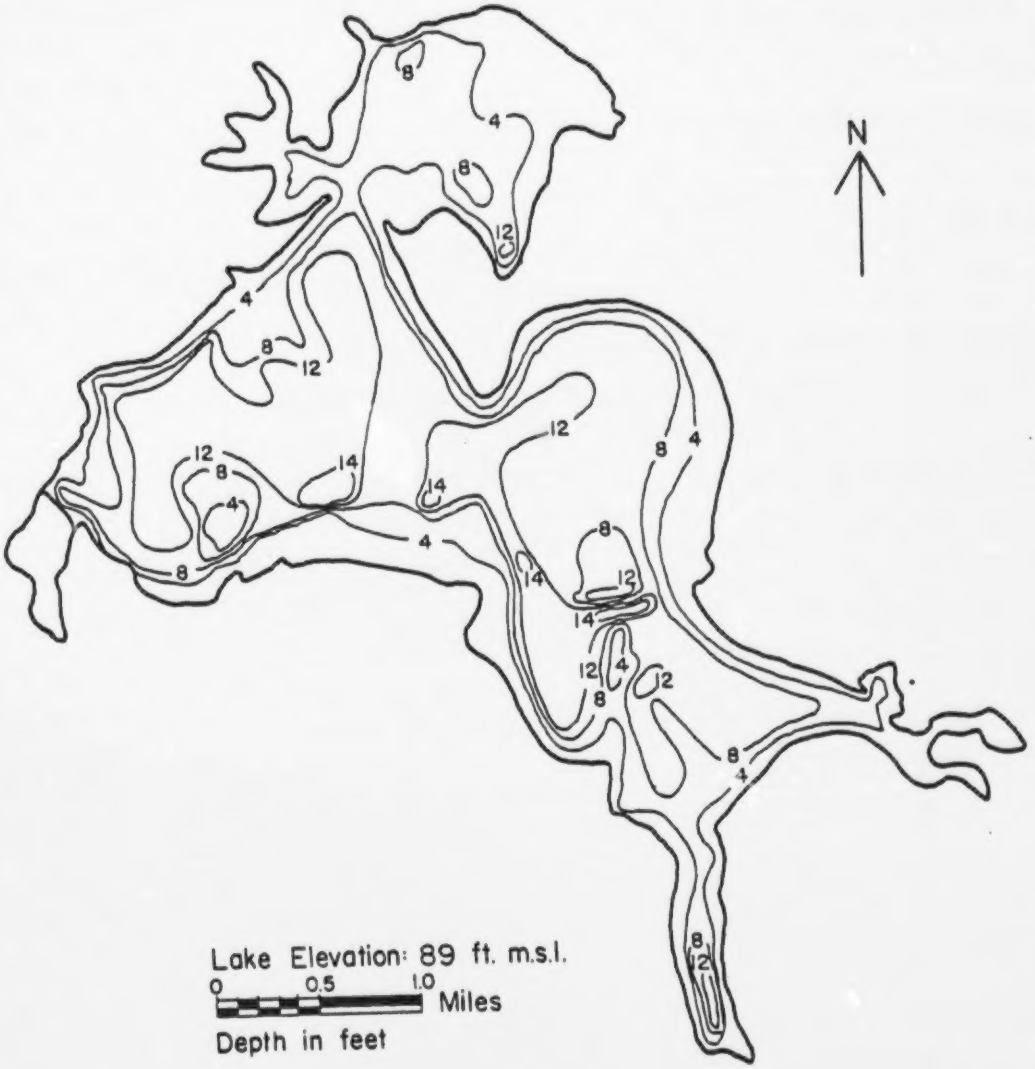
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Figure 7-6. Bathymetric map of Lake Jackson (after Harriss and Turner, 1974).

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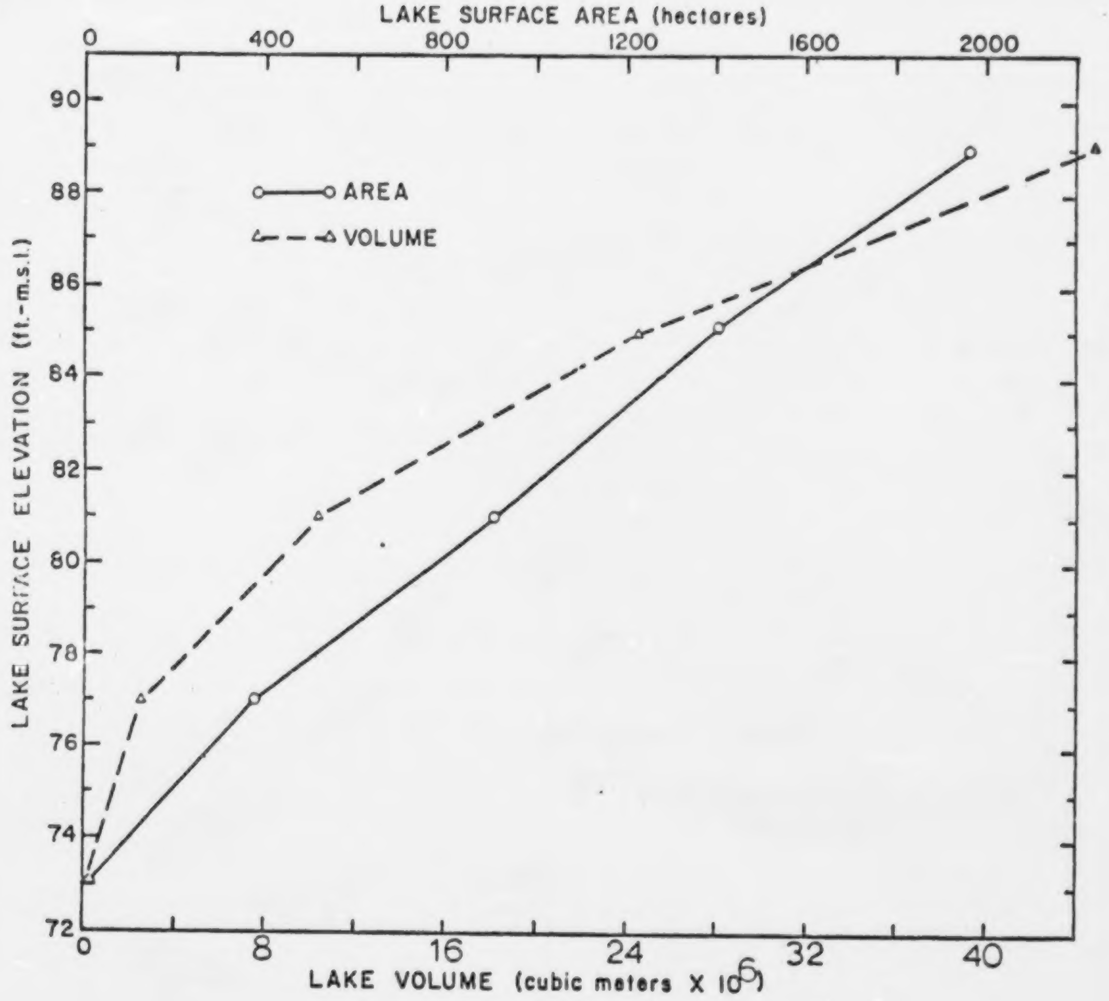

Figure 7-7. Lake surface area and lake volume versus lake surface elevation for Lake Jackson (after Harriss and Turner, 1974)

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TABLE 7-3. CLIMATOLOGICAL PARAMETERS MEASURED DAILY AT QUINCY

Maximum & Minimum 5-foot Shelter Air Temperature
Maximum & Minimum 2-inch Shelter Air Temperature
Chill Hours Below 45 Degree Base*
Chill Hours Below 55 Degree Base*
Warm Hours Above 65 Degree Base*
Maximum & Minimum Surface Soil Temperature
Maximum & Minimum 2-inch Soil Temperature
Maximum & Minimum 4-inch Soil Temperature
Maximum & Minimum 8-inch Soil Temperature
Times of Sunrise & Sunset
Minutes of Sunshine
Solar Radiation in Langleys
Net Radiation in Langleys
Maximum & Minimum Barometric Pressure
Occurrence of Fog, Sleet, Haze, Thunder, Hail, High Wind
Passage of Squall Line, Cold Front, Warm Front, Occluded Front
Hour of Passage of Front
24-hour Rainfall Ending at 0800
Number of Days Since 0.2 Inches or More of Rain
Soil Moisture Index (Inches)
Soil Moisture Percent by Volume
Maximum & Minimum Evaporation Pan Temperature
Miles of Air Moving Over Evaporation Pan
Amount of Evaporation from Pan
Hours of Vegetative Wetting
Vegetative Wetting from Fog, Rain, Dew
Maximum & Minimum Ozone Concentration
Dewpoint Temperature and Relative Humidity at 0100, 0700, 1300, and 1900 EST
Prevailing Wind Direction and Miles of Air Movement 1800 to 0600 EST
Prevailing Wind Direction and Miles of Air Movement 0600 to 1800 EST
Prevailing Wind Direction and Miles of Air Movement 0000 to 2400 EST
Presence of Maritime Tropical, Continental Polar, Arctic Air Masses
Presence of a Low or Wave in the Mexican Gulf
Presence of a Hurricane or Tropical Storm near Mainland

*Recorded November 1 through March 15

The computer calculates mean daily streamflows and total daily precipitation values which are stored permanently on computer tapes, and the five-minute gage readings are then erased. The USGS stores the gage tapes, so the original data are not lost, but it is time consuming and expensive to feed the gage tapes back through the reader and make computer tapes of the original data. In addition, the stream gages measure stream stage, and these readings are converted to streamflows by using rating curves. Since the stream characteristics (and therefore also the rating curves) change with time, it is quite an undertaking to produce ten years of flow data from the original stored gage tapes. It was because of these difficulties that daily rain and streamflow are given instead of actual storm hyetographs and hydrographs. The mean daily lake stage values are also collected by the USGS in a similar manner to streamflow and precipitation values.

The precipitation data measured by FSU were obtained from Dr. Charles Jordan of the Florida State University, Department of Meterology. The data were collected daily from post gages, most of which were sited in the gardens of professors from the Department of Meteorology. The daily data are available on paper from Dr. Jordan and monthly sums of daily values are included in the computer data set.

The climatic data from Quincy were collected under a cooperative arrangement between the University of Florida Institute of Food and Agricultural Sciences, Auburn University, and the National Weather Service. These data are also included in the computer data set.

7-4. LAKE QUALITY DESCRIPTION

7-4-1. Major Pollution Sources

Point Sources--

The major point pollution sources to Lake Jackson are the three runoff creeks which deliver water to the lake. The three watersheds show different characteristic runoff qualities due to their different land use characteristics. The watershed which delivers water to the Meginniss Arm is mostly urbanized, and consequently the Meginniss Arm tributary tends to exhibit the highest loadings of suspended solids and nitrogen. The Ox Bottom Creek watershed is primarily forested and agricultural land, and the loads to the lake from this source are generally lower than those from the Meginniss Arm tributary. The Fords Arm watershed consists of mixed urban, forested and agricultural land.

Harriss and Turner (1974) report intensive quality sampling efforts on 13 storms in the Meginniss Arm watershed and on 8 storms in the Ox Bottom Creek watershed. These data are included in a data set supplied by Turner (personal communication, 1983) and were analyzed by Turner et al. (1975) and Burton et al. (1976, 1977a, 1977b, 1978). They encompass 34 storms in the Meginniss Arm watershed, 23 storms in the Fords Arm watershed, 28 storms in the Ox Bottom watershed, and also some low flow data. The data are described more fully in Section 7-4-3, and are included in the computer data set. The report by Babcock and Rousseau (1976) does not describe any storm sampling, though an assessment of cultural impact on the lake is made. Mason and Belanger (1978) sampled one storm in the Meginniss Arm watershed, but these data are not included since the water flow rates were not measured, and therefore loading rates cannot be calculated. Burnett and Donahue (1982) sampled 8 storms in the Meginniss Arm watershed for nutrients, suspended solids, and conductivity, and these data are included in the computer data set.

Non-Point Sources--

The obvious non-point pollution and nutrient sources to the lake are those parts of the watershed which do not drain through the three principal runoff creeks. Since water entering the lake from these sources has not been quantified or sampled, non-point loadings must be estimated from a consideration of land use in these areas and estimates of how much water they contribute to the lake.

Precipitation--

Data on precipitation water quality are presented from two studies. The first study was provided by Turner (personal communication, 1983). The study presents total deposition of nutrients, collected two to twelve times a month. The samples were collected at the Public Services Building on the west side of the FSU campus in Tallahassee from October 1973 to May 1975, and at the Ox Bottom Creek gage from December 1974 to May 1975.

The second study is from Brezonik et al. (1983), and it also presents measurements of total nutrient deposition taken at the Public Services Building on the FSU campus. The measurements were taken one to three times a month from January 1978 to November 1979. The data from both these studies are given in the computer data set.

7-4-2. Biochemical Data

Sampling Studies--

The biochemical data from Lake Jackson are drawn from four water quality surveys by Harriss and Turner (1974), Babcock and Rousseau (1976), Mason and Belanger (1978), and Burnett and Donahue (1982). The parameters measured and the frequency and duration of measurement are given in the following section.

Unfortunately, the four studies did not all use the same station locations in their surveys, so that it is not always possible to compare their results directly. The locations of the sampling stations are shown in Figures 7-8 to 7-11. The positions of the sampling stations in the Harriss and Turner study are given in Tables 7-4 and 7-5, and the positions of the sampling stations in the Babcock and Rousseau study are given in Table 7-6. Unfortunately, the study by Mason and Belanger does not give the map grid positions of the stations, defining their positions instead by giving bearings to landmarks visible from the lake. The positions of the sampling stations used in the Burnett and Donahue study are given in Tables 7-7 and 7-8.

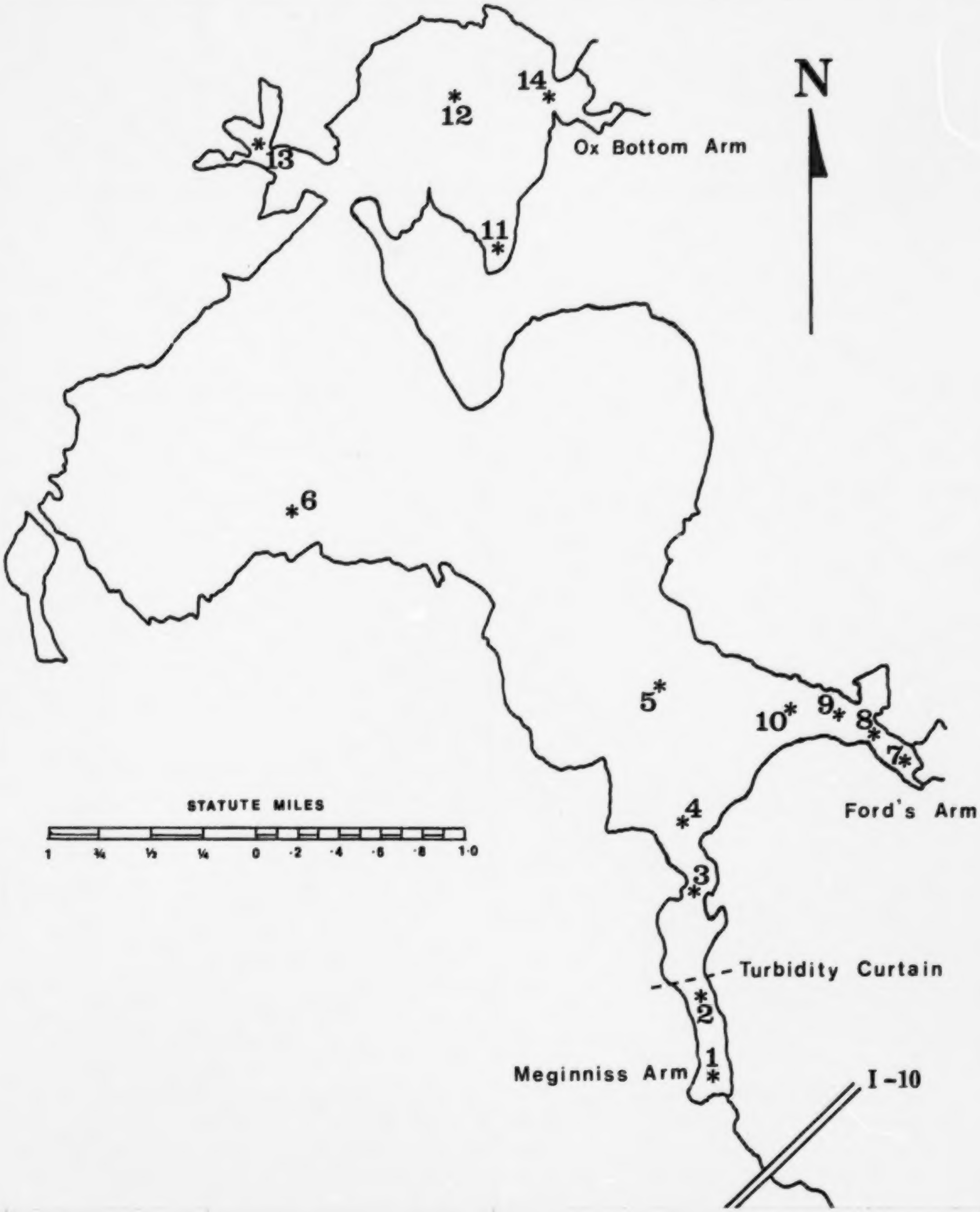
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Figure 7-8. Locations of lake sampling stations from the Harriss and Turner study (adapted from: Harriss and Turner, 1974; Mason and Belanger, 1978).

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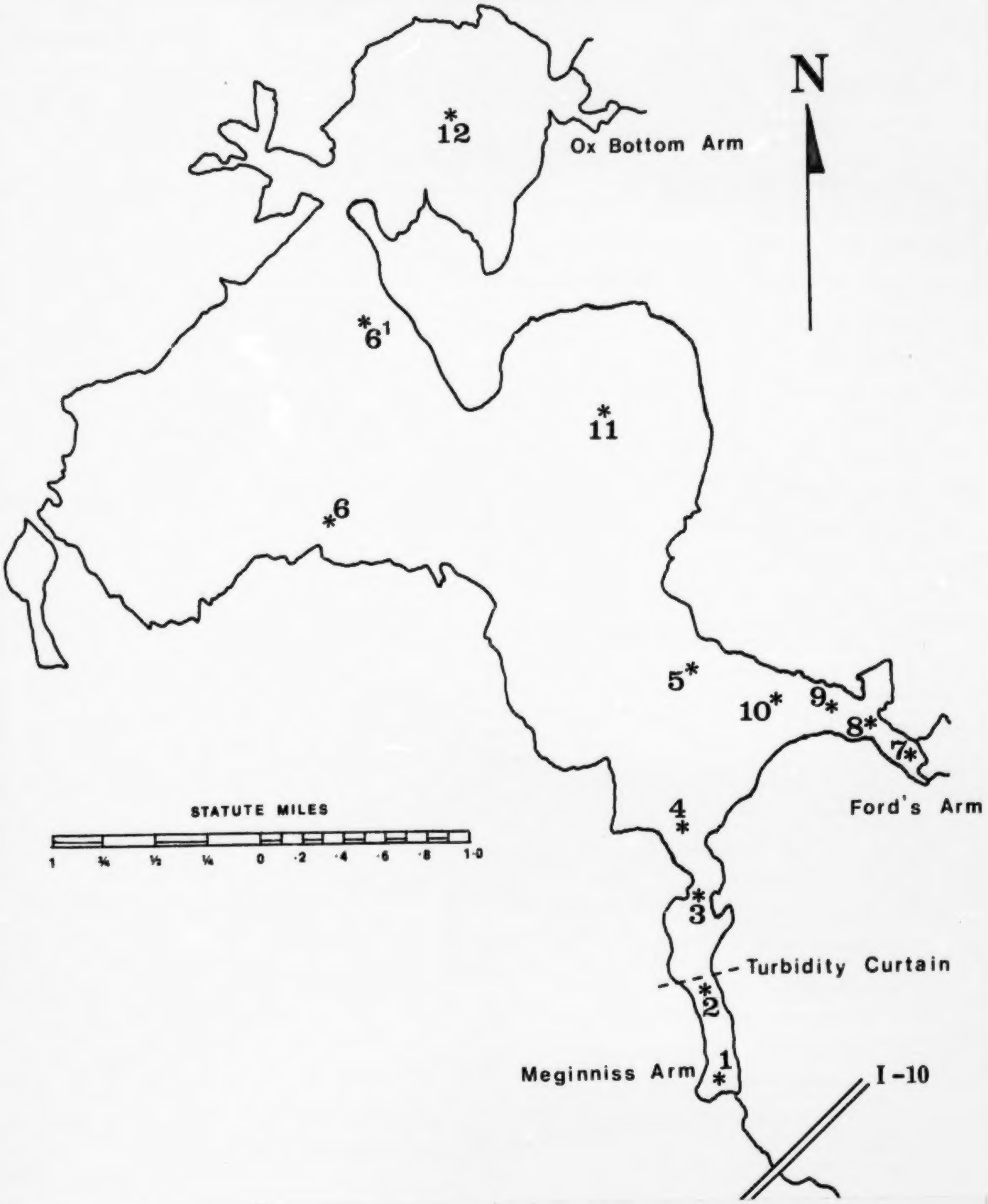
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Figure 7-9. Locations of lake sampling stations from the Babcock and Rousseau study (adapted from: Babcock and Rousseau, 1976; Mason and Belanger, 1978).

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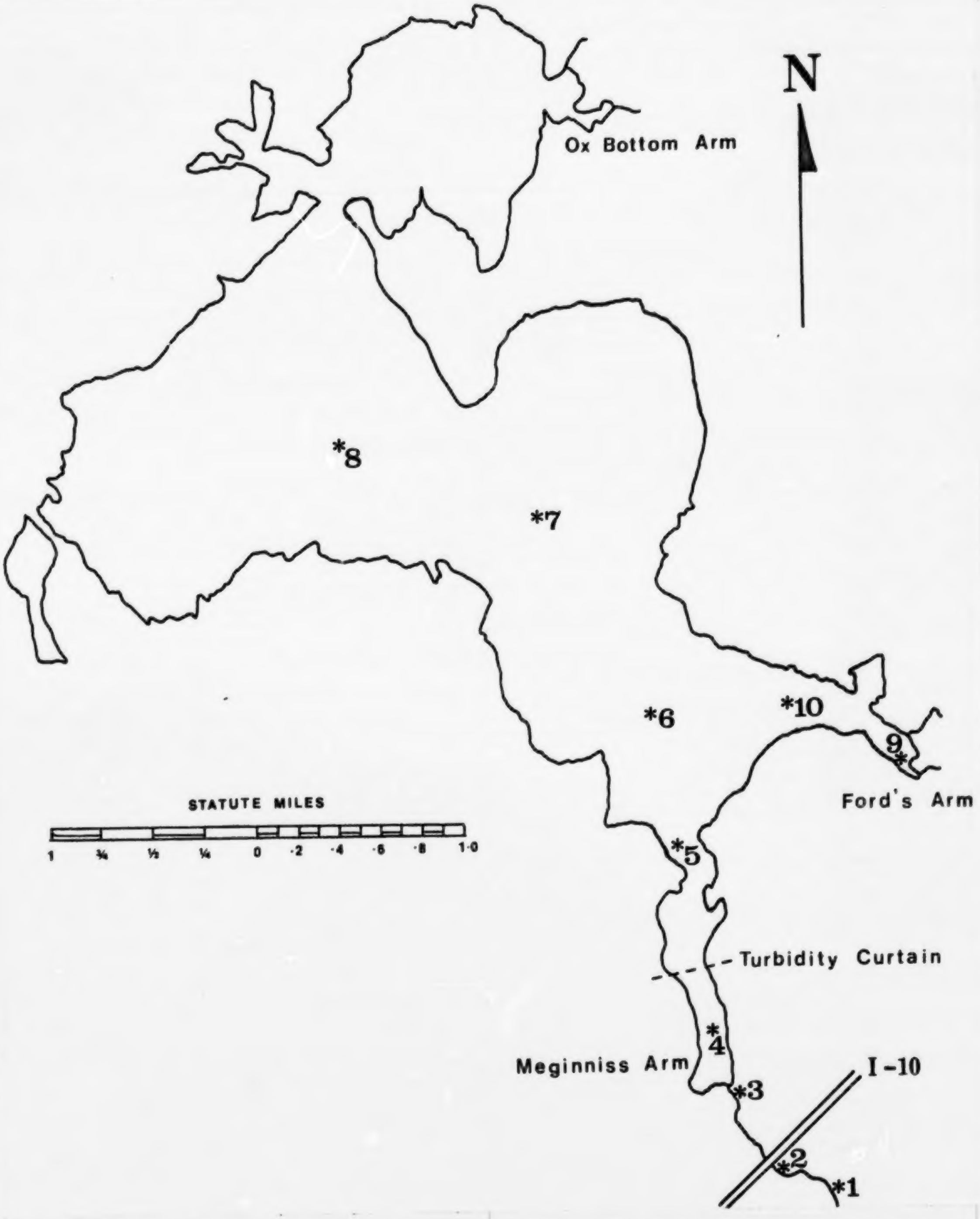
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Figure 7-10. Locations of lake sampling stations from the Mason and Belanger study (adapted from Mason and Belanger, 1978).

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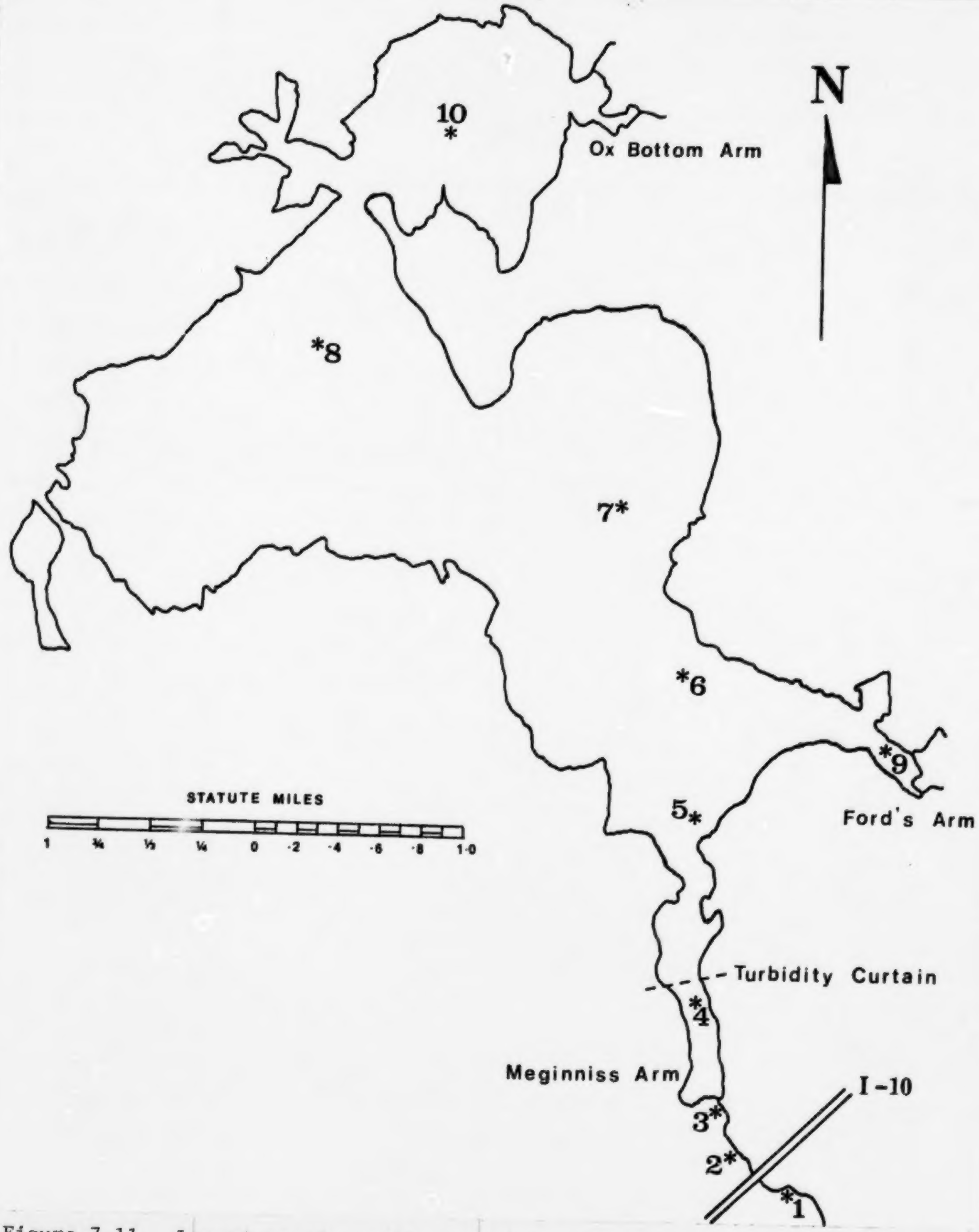
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Figure 7-11. Locations of sampling stations from the Burnett and Donahue study (adapted from: Burnett and Donahue, 1982; Mason and Belanger, 1978).

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TABLE 7-4. POSITIONS OF LAKE SAMPLING STATIONS IN HARRISS AND TURNER STUDY (after Harriss and Turner, 1974)

Station No.	STORET Station No.	Longitude Deg.	Longitude Min.	Longitude Sec.	Latitude Deg.	Latitude Min.	Latitude Sec.
L1	22.02.0040	84	18	16 W	30	29	22 N
L2	22.02.0041	84	18	21 W	30	29	36 N
L3	22.02.0042	84	18	32 W	30	30	2 N
L4	22.02.0043	84	18	34 W	30	30	17 N
L5	22.02.0038	84	18	40 W	30	30	56 N
L6	22.02.0044	84	20	26 W	30	31	46 N
L7	22.02.0045	84	17	25 W	30	30	30 N
L8	22.02.0046	84	17	31 W	30	30	38 N
L9	22.02.0047	84	17	47 W	30	30	42 N
L10	22.02.0048	84	17	58 W	30	30	45 N
L11	22.02.0049	84	19	23 W	30	32	42 N
L12	22.02.0050	84	19	36 W	30	33	14 N
L13	22.02.0037	84	20	31 W	30	33	12 N
L14	- none -						

TABLE 7-5. POSITIONS OF WATERSHED SAMPLING STATIONS IN HARRIS AND TURNER STUDY (after Harriss and Turner, 1974)

Station No.	STORET Station No.	Longitude Deg.	Longitude Min.	Longitude Sec.	Latitude Deg.	Latitude Min.	Latitude Sec.
W1A	22.02.0051	84	18	3 W	30	29	2 N
W1B	22.02.0052	84	18	11 W	30	29	5 N
W2	22.02.0053	84	17	53 W	30	28	36 N
W2A	22.02.0054	84	17	53 W	30	28	34 N
W2B	22.02.0055	84	17	55 W	30	28	36 N
W3	22.02.0056	84	17	41 W	30	28	39 N
W4	22.02.0057	84	17	38 W	30	28	37 N
W5	22.02.0058	84	17	19 W	30	28	33 N
W5A	22.02.0059	84	17	36 W	30	28	38 N
W6	22.02.0060	84	17	20 W	30	27	59 N
W7	22.02.0061	84	17	21 W	30	27	58 N
W8	22.02.0062	84	18	9 W	30	28	48 N
W9	22.02.0063	84	17	53 W	30	28	9 N
W10	22.02.0064	84	16	42 W	30	29	59 N
W11	22.02.0065	84	16	40 W	30	30	48 N
W12	- none -						

TABLE 7-6. POSITIONS OF LAKE SAMPLING STATIONS IN BABCOCK AND ROUSSEAU STUDY

Station Number	Longitude			Latitude		
	Deg.	Min.	Sec.	Deg.	Min.	Sec.
1	84	18	16 W	30	29	22 N
2	84	18	21 W	30	29	36 N
3	84	18	32 W	30	30	2 N
4	84	18	34 W	30	30	17 N
5	84	18	40 W	30	30	56 N
6	84	20	26 W	30	31	46 N
6*		?			?	
7	84	17	25 W	30	30	30 N
8	84	17	31 W	30	30	38 N
9	84	17	47 W	30	30	42 N
10	84	17	58 W	30	30	45 N
11		?			?	
12	84	19	36 W	30	33	14 N

*used in October 1974

TABLE 7-7. POSITIONS OF LAKE SAMPLING STATIONS IN BURNETT AND DONAHUE STUDY

Station Number	Longitude			Latitude		
	Deg.	Min.	Sec.	Deg.	Min.	Sec.
1	84	18	1 W	30	29	1 N
1*	84	17	57 W	30	28	56 N
2	84	18	6 W	30	29	3 N
3	84	18	5 W	30	29	4 N
4	84	18	18 W	30	29	28 N
5	84	18	30 W	30	30	19 N
6	84	18	38 W	30	30	51 N
7	84	19	5 W	30	31	35 N
8	84	20	6 W	30	32	25 N
9	84	17	15 W	30	30	28 N
10	84	19	55 W	30	33	5 N

*used after September 1981

TABLE 7-8. POSITIONS OF WATERSHED SAMPLING STATIONS IN BURNETT AND DONAHUE STUDY

Station Number	Location
1	Meginniss Arm Tributary, just south of I-10
2	Meginniss Arm Tributary, just north of I-10
3	Effuent of settling ponds near entrance to Meginnis Arm
101	Tallahassee Mall, Allen Rd., North Tallahassee
102	Northwood Mall, Boulevard St., North Tallahassee
103	Entrance to Meginniss Arm

Lake Conditions--

Average concentrations of nutrients at different points in the lake are not presented because the sampling stations were not at the same positions throughout the study period. In general, the northern portion of the lake exhibits surface dissolved oxygen levels near saturation levels, and fairly stable conditions. The southern portion of the lake tends to show less stable conditions due to degradation of water quality resulting from storm runoff from the more urbanized areas of the lake's watershed. The Meginniss Arm, and to a lesser extent Fords Arm, exhibit highly fluctuating water quality. There is a pattern of storm runoff producing temporary periods of high turbidity and nutrient loading, frequently followed by algal blooms. The average water conditions in these two sections are significantly less healthy than those in the northern part of the lake.

7-4-3. Measurement Listing

A summary of the lake quality surveys, including a listing of study periods and parameters measured, is given in Table 7-9. A similar summary of stormwater runoff water quality surveys is presented in Table 7-10. A methodology for all the water sampling techniques is not given because a different methodology would have to be presented for each of the five studies. This would require more space than is reasonable, and readers are referred to the methodology sections in the original reports.

7-5. COMPUTER DATA SET

The data supplied in the computer data set are described in Tables 7-2, 7-3, 7-9, and 7-10. The periods when hydrologic data are missing are shown in Figure 7-4.

7-6. REFERENCES

1. Babcock, S., and Rousseau, R., "Study II. Lake Jackson Studies," State of Florida Game and Fresh Water Fish Commission, Tallahassee, FL, 1976.

2. Brezonik, P.L., Hendry, C.D., Jr., Edgerton, E.S., Schulze, R.L., and Crisman, T.L., "Acidity, Nutrients and Minerals in Atmospheric Precipitation Over Florida: Deposition Patterns, Mechanisms, and Ecological Effects," EPA 600/3-83-004 (NTIS PB83-165827), Environmental Protection Agency, Corvallis, OR, 1983.

3. Burnett, W.C., and Donahue, C.R., "Lake Jackson Water Quality Investigations (1978-1981)," Department of Oceanography, Florida State University, Tallahassee, FL, 1982.

TABLE 7-9. SUMMARY OF LAKE JACKSON WATER QUALITY SURVEYS.

Source Report	Study Period	Measurement Frequency	Number of Lake Stations Sampled	Parameters Measured in the Study
Harriss and Turner (1974)	July 1971-June 1974	biweekly	11	Temperature, pH, Alkalinity, D.O., Secchi depth, Turbidity, Suspended Solids, Conductivity, Color, Chloride, Sulphate, Silicon, Nitrate, Nitrite, Ammonia, Orthophosphate, Dissolved phosphate, Total phosphates, Phytoplankton
Babcock and Rousseau (1976)	October 1974-April 1976	quarterly	12	Depth, Secchi depth, Conductivity, pH, D.O., Temperature, Total Residue, Sulfate, Turbidity, Calcium, Magnesium, Sodium Potassium, Chloride, Iron, Nitrate, Ammonia, Organic Nitrogen, Orthophosphate, Total Phosphate
Mason and Belanger (1978)	December 1976-November 1977	monthly	10	Silica, Temperature, pH, Alkalinity, Transmissivity, D.O., Nitrate, Nitrite, Ammonia, Organic Nitrogen, Orthophosphate, Total Phosphate, Chlorophyll-a, Turbidity, Suspended Solids, Chloride, Sulfate, Conductivity
Burnett and Donahue (1982)	December 1977-June 1981	monthly	10	Temperature, pH, Alkalinity, D.O., Secchi depth, Turbidity, Suspended Solids, Conductivity, Chloride, Sulfate, Silicon, Nitrate, Nitrite, Ammonia, Organic Nitrogen, Orthophosphate, Total Phosphate, Chlorophyll-a

TABLE 7-10. SUMMARY OF WATERSHED STORM RUNOFF WATER QUALITY SURVEYS.

Data Source	Watershed	Study Period	Number of Storms	Parameters Measured in Surveys
R.R. Turner (personal communication, 1983)	Meginniss Arm	August 1973-May 1975	34	Time, Flow, Turbidity, Volatile Dissolved Solids, Volatile Suspended Solids, Dissolved Solids, Suspended Solids, Conductance, Chloride, Silicon, Nitrate, Nitrite, Ammonia, Orthophosphate, Dissolved Phosphate, Total Phosphate
R.R. Turner (personal communication, 1983)	Fords Arm	August 1973-May 1975	23	Time, Flow, Turbidity, Volatile Dissolved Solids, Volatile Suspended Solids, Dissolved Solids, Suspended Solids, Conductance, Chloride, Silicon, Nitrate, Nitrite, Ammonia, Orthophosphate, Dissolved Phosphate, Total Phosphate
R.R. Turner (personal communication, 1983)	Ox Bottom	September 1973-May 1975	28	Time, Flow, Turbudity, Volatile Dissolved Solids, Volatile Suspended Solids, Dissolved Solids, Suspended Solids, Conductance, Chloride, Silicon, Nitrate, Nitrite, Ammonia, Orthophosphate, Dissolved Phosphate, Total Phosphate
Burnett and Donahue (1982)	Meginniss Arm	April 1978-June 1981	8	Time, Flow, Turbidity, Suspended Solids, Conductivity, Chloride, Silicon, Nitrate, Nitrite, Orthophosphate, Total Phosphate, pH, Alkalinity, Petroleum Hydrocarbons*

*The hydrocarbons data are not included on the data tape.

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4. Burton, T.M., Turner, R.R., and Harriss, R.C., "The Impact of Highway Construction on a North Florida Watershed," Water Resources Bulletin, Vol. 12, No. 3, June 1976, pp. 529-583.

5. Burton, T.M., Turner, R.R., and Harriss, R.C., "Nutrient Export from Three North Florida Watersheds in Contrasting Land Use," in Correll, D.T. (editor), Watershed Research in Eastern North America, Chesapeake Bay Center for Environmental Studies, Smithsonian Institution, Edgewater, MD, 1977a, pp. 323-342.

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12. Turner, R.R., Harriss, R.C., Burton, T.M., and Laws, E.A., "The Effect of Urban Land Use on Nutrient and Suspended-Solids Export from North Florida Watersheds," in Howell, F.G., Gentry, J.B., and Smith, M.H., (editors), Mineral Cycling in Southeastern Ecosystems, CONF-740513, U.S. Energy Research and Development Administration, Washington, DC, 1975, pp. 868-888.

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SECTION 8

POTOMAC ESTUARY

8-1. INTRODUCTION

Flowing past the nation's capital, the Potomac River-Estuary is at once one of the most visible and well studied of all U.S. estuaries. Major monitoring and modelling efforts date from the early 1960's when dissolved oxygen problems became increasingly apparent; the 112 mile (180 km) reach from Washington, DC to Chesapeake Bay has witnessed many data collection surveys, including recent intensive studies by the USGS and EPA.

Early restoration efforts centered on implementation of increasingly high levels of treatment at regional sewage treatment plants. These have generally succeeded in eliminating DO and algae problems in the Potomac due to point source waste inputs. However, eutrophication problems caused by both point and non-point source inflows remain and are under current study. Management approaches for the Potomac are described by Librach et al. (1982).

8-2. SOURCE LITERATURE

Most of the same models that have been applied to the Delaware Estuary (see Section 9) have also been applied to the Potomac. For instance, the "Thomann model" (Pence et al., 1968) was applied by Hetling and O'Connell (1968) for the calculation of DO levels. Dispersion coefficients were also obtained by Hetling and O'Connell (1966) from dye studies. Summaries of use of the Delaware models on the Potomac are provided by Ward and Espey (1971), Thomann (1972) and O'Connor et al. (1976). The work was extended by Thomann et al. (1974) for phytoplankton modelling in the Potomac. The MIT Dynamic Network Model was tested for salinity predictions in both the Delaware and Potomac Estuaries (Thatcher and Harleman, 1972a, 1972b). It was later extended to nutrient dynamics, with an extensive case study on the Potomac (Najarian and Harleman, 1975, 1977). Najarian and Taft (1981) also developed rate constants for nutrient models with the Potomac in mind.

EPA's Dynamic Estuary Model (DEM) has been applied to the Potomac by Roesch et al. (1979) and Ambrose and Roesch (1982). Considerable modelling information is available from the DEM and MIT model studies, including Mannings roughness coefficients and dispersion coefficients.

Both have relied upon physical data assembled by Jaworski and Clark (undated) at what is now EPA's Central Regional Laboratory (formerly the Annapolis Field Office).

The most recent modelling activity on the estuary has again centered on the Delaware model formulation. In a large study by Hydroqual Inc., Thomann and Fitzpatrick (1982) have developed the Potomac Eutrophication Model for the District of Columbia, Department of Environmental Services. Much of the modelling information presented in this section, particularly recent load information, is taken from this report.

Monitoring of the Potomac has been conducted over many years by the EPA, USGS, Corps of Engineers, state and local agencies, and consultants. The recent data assembled for this report were collected by these groups, especially EPA and the USGS, during 1977-1980 and are referenced in detail below in Section 8-4-3.

8-3. RIVER BASIN DESCRIPTION

8-3-1. Study Area

The tidal Potomac River and its estuary are shown in Figures 8-1 and 8-2. The study section runs 180.7 km (112.3 mi) from Chain Bridge in Washington, DC, to Point Lookout on Chesapeake Bay. The river may be broken into four characteristic sections; the section upstream of Chain Bridge is purely riverine (it is not significantly affected by the tide), the 61.6 km (38.3 mi) segment from Chain Bridge to Quantico is a tidal river, the 45.2 km (28.0 mi) section from Quantico to the Route 301 Bridge near Morgantown is a transitional zone between tidal river and estuary, and the 73.9 km (46.0 mi) section from Morgantown to Point Lookout is entirely estuarine. The tidal river zone is composed entirely of fresh water, but it usually experiences cyclical reversals of flow due to tidal influence, the transition zone contains both fresh and saline water, and the estuarine zone is saline and predominantly influenced by tidal effects.

The total watershed area of the Potomac Estuary is 38,000 km^2 (14,670 mi^2), and 29,940 km^2 (11,560 mi^2) of this area drains into the Potomac River upstream of Little Falls, MD. Little Falls is just 1.9 km (1.2 mi) upstream of Chain Bridge, the furthest upstream station of the study area. Since 79% of the total watershed drains into the river upstream of the study area, the river flows at Chain Bridge exert a dominant influence on flows in the study area.

The major point inputs to the estuary are the sewage treatment plants (STP's) between Washington, DC, and Occoquan Bay. The District of Columbia-Blue Plains plant is much the most significant of these, contributing 75% to 80% of the total STP flow. The major non-point input sources to the study section are the many small tributaries that drain into the estuary.

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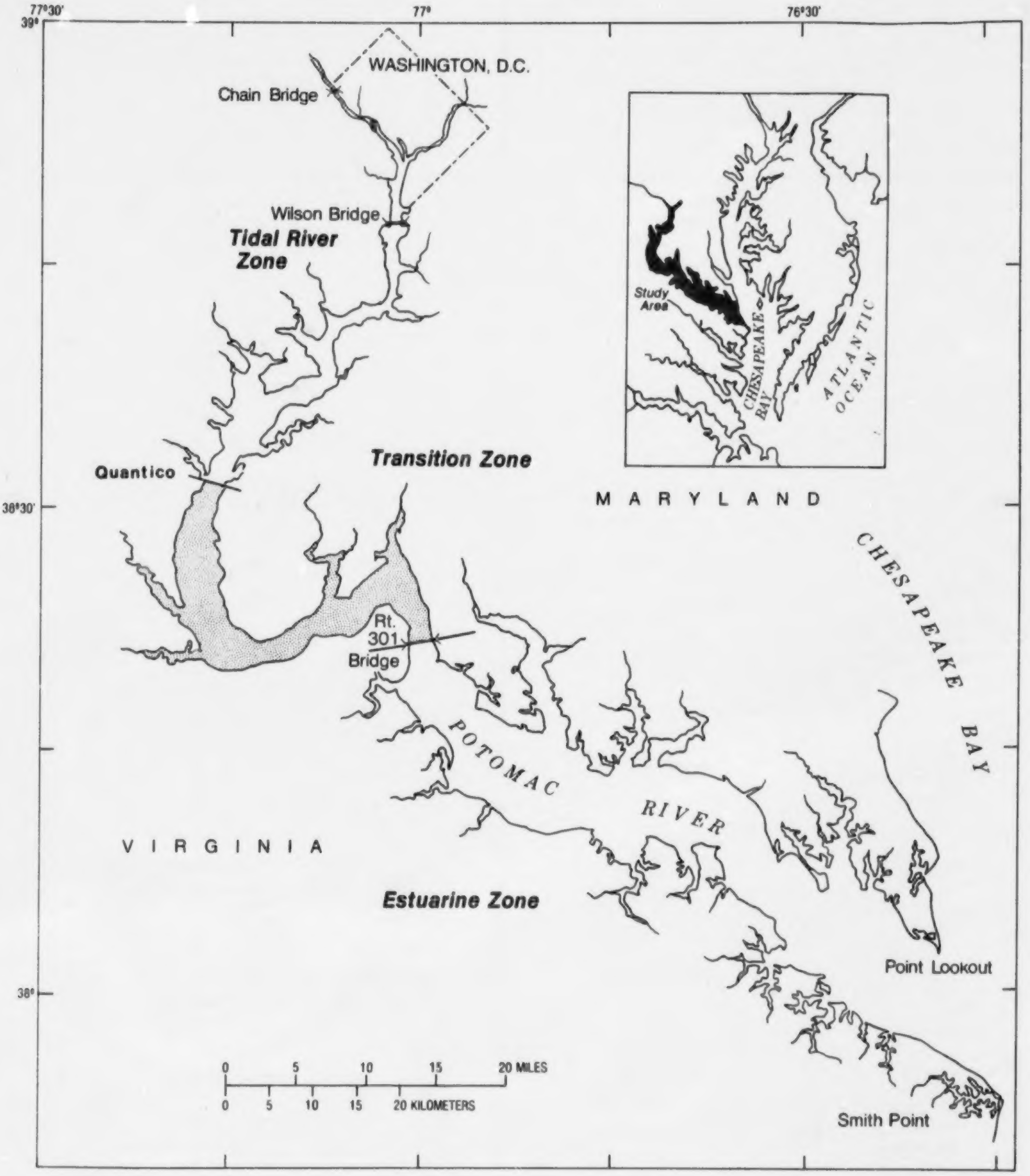
77°30'
77°
76°30'
39°
38°30'
38°
WASHINGTON, D.C.
Chain Bridge
Wilson Bridge
Tidal River Zone
Quantico
Transition Zone
MARYLAND
CHESAPEAKE BAY
Rt. 301 Bridge
POTOMAC RIVER
VIRGINIA
Estuarine Zone
Point Lookout
Smith Point
Study Area
CHESAPEAKE BAY
ATLANTIC OCEAN
0 5 10 15 20 MILES
0 5 10 15 20 KILOMETERS

Figure 8-1. Tidal Potomac River and Estuary (after Blanchard and Hahl, 1981)

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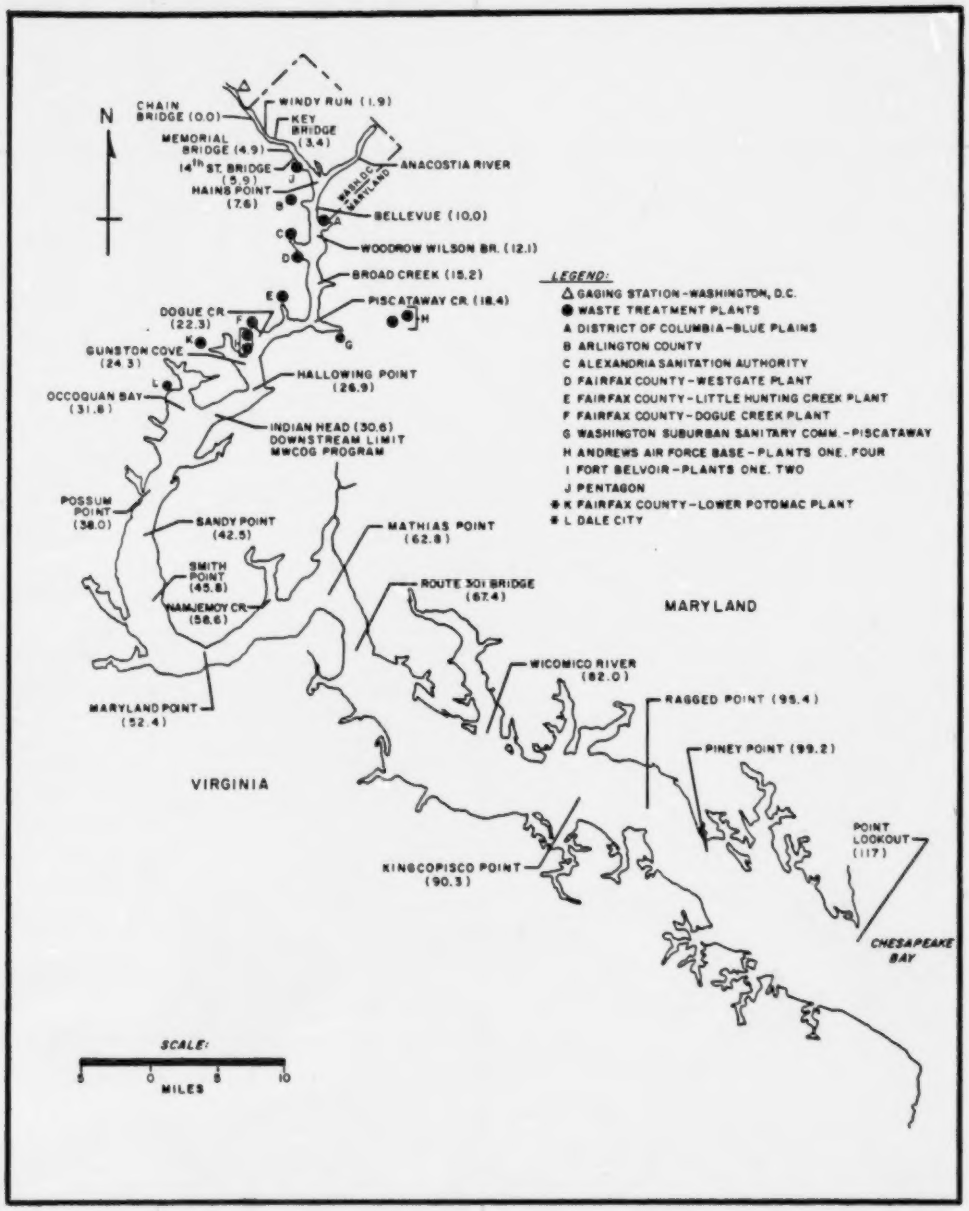
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CHAIN BRIDGE (0.0)
WINDY RUN (1.9)
KEY BRIDGE (3.4)
MEMORIAL BRIDGE (4.9)
14th ST. BRIDGE (5.9)
HAINS POINT (7.6)
ANACOSTIA RIVER
WASH. D.C.
MARYLAND
BELLEVUE (10.0)
WOODROW WILSON BR. (12.1)
BROAD CREEK (15.2)
PISCATAWAY CR. (18.4)
DOGUE CR. (22.3)
GUNSTON COVE (24.3)
HALLOWING POINT (26.9)
OCCOQUAN BAY (31.8)
INDIAN HEAD (30.6) DOWNSTREAM LIMIT MWCOG PROGRAM
POSSUM POINT (38.0)
SANDY POINT (42.5)
SMITH POINT (45.8)
NANJEMOY CR. (56.6)
MATHIAS POINT (62.8)
ROUTE 301 BRIDGE (67.4)
MARYLAND
MARYLAND POINT (52.4)
WICOMICO RIVER (82.0)
RAGGED POINT (95.4)
PINEY POINT (99.2)
VIRGINIA
KINGCOPISCO POINT (90.3)
POINT LOOKOUT (117)
CHESAPEAKE BAY
A
B
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LEGEND:
△ GAGING STATION - WASHINGTON, D.C.
● WASTE TREATMENT PLANTS
A DISTRICT OF COLUMBIA - BLUE PLAINS
B ARLINGTON COUNTY
C ALEXANDRIA SANITATION AUTHORITY
D FAIRFAX COUNTY - WESTGATE PLANT
E FAIRFAX COUNTY - LITTLE HUNTING CREEK PLANT
F FAIRFAX COUNTY - DOGUE CREEK PLANT
G WASHINGTON SUBURBAN SANITARY COMM. - PISCATAWAY
H ANDREWS AIR FORCE BASE - PLANTS ONE, FOUR
I FORT BELVOIR - PLANTS ONE, TWO
J PENTAGON
* K FAIRFAX COUNTY - LOWER POTOMAC PLANT
* L DALE CITY
SCALE:
5 0 5 10
MILES

Figure 8-2. Location map of STP's discharging to the upper Potomac Estuary (after Thomann and Fitzpatrick, 1982).

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The locations of major reference points in the estuary are shown in Figure 8-2 and given in Table 8-1.

8-3-2. Hydrologic Data

Point Inflows--

The most significant point inflow to the study area is from the Potomac River headwaters above Chain Bridge. Since 79% of the watershed's 38,000 km^2 (14,670 mi^2) drains into the Potomac above Chain Bridge, it is inevitable that flows at Chain Bridge will have a major impact on flows in the lower part of the estuary. The USGS gages the Potomac River flows at Little Falls, 1.9 km (1.2 mi) upstream from Chain Bridge, and these flows are an excellent estimate of flow passing under Chain Bridge; these are shown in Figure 8-3 for the years 1977, 1978 and 1979. The Potomac River is largely uncontrolled, and as can be seen from the hydrographs in Figure 8-2, flows can rise and fall very abruptly in response to rain storms.

The other main source of point inflows to the estuary is flow from STP's. The positions of these facilities are given in Table 8-2, and they are shown in Figure 8-2. Information on STP discharges prior to the late 1970's is sketchy, but discharge data from 1977 through 1979 are more complete. The District of Columbia-Blue Plains STP accounts for 75% to 80% of the STP discharge to the river. Summaries of the Blue Plains average monthly discharges for the years 1969, 1970, 1977, 1978, 1979, are given in Tables 8-3 and 8-4. Mean annual STP discharges for the years 1977, 1978, 1979 are given in Table 8-5.

The computer data set contains intensive low flow surveys during 1977 and 1978 performed by the EPA, and these include STP flow and loading data. The computer data set also includes river quality data from CSO studies by O'Brien and Gere during 1979 and 1980 (unpublished memoranda). The STP flows that were measured during these studies are included in an addendum to this report. The O'Brien and Gere studies included two river surveys during storms, and flow and loading data from these storms are also given in the computer data set as input data for the DEM model. The USGS performed water quality surveys in the estuary from 1977 through 1981 (see measurement listing for references), and the data from these studies include information on Blue Plains STP discharges. USGS data from 1977 and 1978 are included in the computer data set, but the more recent data must be retrieved from STORET; the USGS station numbers for STORET retrievals are given in Section 8-4-2.

The USGS gages some, but not all, of the tributaries to the estuary. Since most of the tributaries are not gaged near their junctions with the estuary, it is not convenient to treat them simply as point sources to the estuary. The tributary flows are therefore considered in the following section.

TABLE 8-1. LOCATIONS OF PROMINENT REFERENCE POINTS ALONG THE POTOMAC ESTUARY (after Jaworski and Clark, undated)

Landmark Points	Distance below Chain Bridge (mi)	Distance below Chain Bridge (km)
Marbury Point	10.55	17.0
Fox Ferry Point	7.50	12.1
Jones Point	12.34	19.9
Indian Queen Point	14.90	24.0
Hatton Point	17.30	27.8
Sheridon Point	18.65	30.0
Mockley Point	18.60	29.9
Bryan Point	19.80	31.9
Ferry Point	21.90	35.2
Whitestone Point	24.10	38.8
Pomonkey Point	26.40	42.5
Sycamore Point	29.80	48.0
High Point	31.30	50.4
Deep Point	34.00	54.7
Cockpit Point	35.90	57.8
Douglas Point	43.90	70.7
Simms Point	46.80	75.3
Marlboro Point	49.35	79.4
Blossom Point	59.10	95.1
Upper Cedar Point	60.10	96.7
Mathias Point	62.70	100.9
Persimmon Point	66.20	106.5

(Continued)

TABLE 8-1. (Concluded)

Landmark Points	Distance below Chain Bridge (mi)	(km)
Lower Cedar Point	68.80	110.7
Stony Point	72.70	117.0
Swan Point	74.20	119.4
White Point	75.00	120.7
Gum Bar Point	76.00	122.3
Church Point	77.00	123.9
Cobb Point	80.25	129.1
Waterloo Point	84.30	135.7
Crunch Point	88.10	141.8
Ragged Point	95.40	137.4
Deep Point	102.80	165.4
Kitts Point	105.20	169.3
Lawson Point	106.60	171.6
Chain Bridge	0	0
Key Bridge	3.35	5.4
Theodore Roosevelt Bridge	4.45	7.2
Memorial Bridge	4.85	7.8
14th Street Bridges		
a. George Mason	5.90	9.5
b. Rochambeau	6.05	9.7
Woodrow Wilson Bridge	12.10	19.5
301 Bridge	67.40	108.5

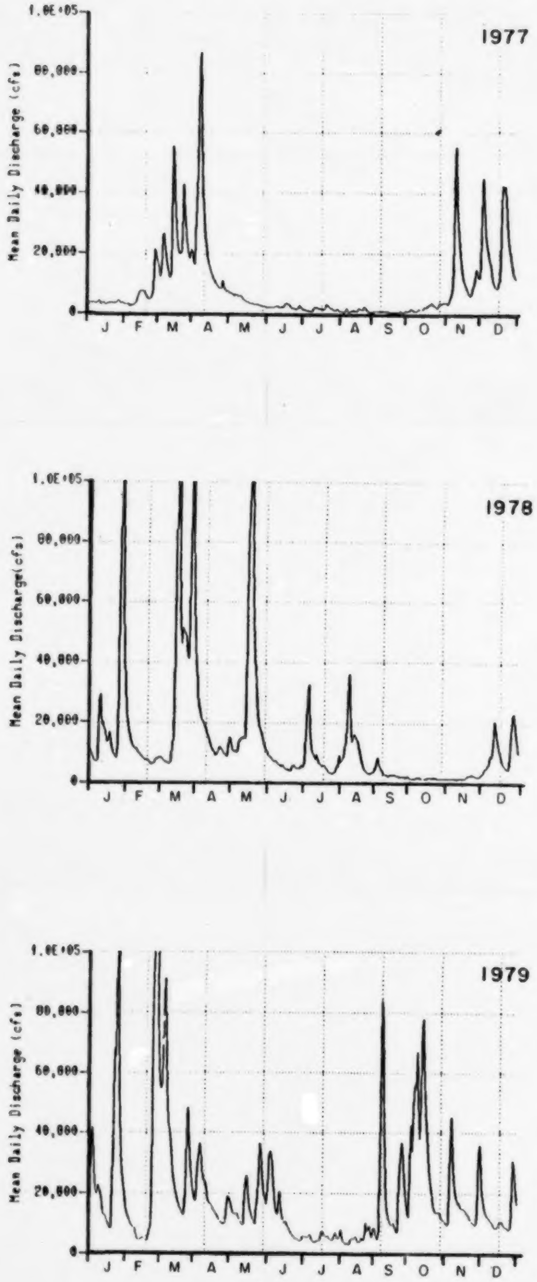

Figure 8-3. River flows at Chain Bridge, 1977,1978, 1979 (after Thomann and Fitzpatrick, 1982).

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TABLE 8-2. MAJOR WASTEWATER DISCHARGE LOCATIONS IN THE UPPER POTOMAC ESTUARY (after Jaworski and Clark, undated)

Facility	Receiving Stream	Distance from Chain Bridge* (mi)	Distance from Chain Bridge* (km)	Expanded Thomann Model Segment**
Combined D.C. system sewer overflow	Potomac Estuary	4.0	6.4	4
Pentagon	Potomac Estuary	5.8	9.3	6
Arlington	Four Mile Run			12
District of Columbia	Potomac Estuary	10.4	16.7	13
Alexandria	Hunting Creek	12.4	20.0	15
Fairfax-West Gate	Hunting Creek Embayment	12.8	20.6	16
Piscataway	Piscataway Embayment	18.3	29.5	22
Andrews AFB No. 1	Piscataway Creek	18.3	29.5	22
Andrews AFB No. 2	Piscataway Creek	18.3	29.5	22
Fairfax Hunting Cr.	Little Hunting Creek	20.0	32.2	24
Fairfax Douge Creek	Dogue Creek	22.5	36.2	27
Fairfax Lower Potomax	Pohick	24.5	39.4	28
Ft. Belvoir No. 1	Gunston Cove	24.5	39.4	28
Ft. Belvoir No. 2	Gunston Cove	24.5	39.4	28

*If discharge is into an embayment distance is to midpoint of embayment. All distances in statute miles.

TABLE 8-3. BLUE PLAINS STP MEAN MONTHLY FLOWS, 1969 AND 1970 (after Thomann and Fitzpatrick, 1982)

Month	Year and Source 1969 Siddique	1969 Freedman	1970 Siddique	1969 Freedman
January	232 mgd	N/A	248 mgd	N/A
February	228	"	255	"
March	237	"	252	"
April	235	"	261	269.3 mgd
May	242	"	258	274.9
June	265	"	258	270.3
July	263	"	269	271.2
August	273	"	265	266.7
September	258	"	259	260.5
October	236	"	245	247.0
November	238	"	253	253.1
December	245	"	238	250.1
Annual Average	246	–	255	262.6 (9 months)

1 mgd = 1.547 cfs

N/A = Not Available

Source: Siddique (1981) and Freedman (1981), personal communications

TABLE 8-4. BLUE PLAINS STP MEAN MONTHLY FLOWS, 1977-1979 (after Thomann and Fitzpatrick, 1982)

Month	Mean Flow in mgd, Discharge Point 002* 1977	1978	1979
January	258	326	304
February	260	281	272
March	274	304	305
April	282	282	294
May	276	301	293
June	280	297	315
July	275	309	303
August	280	325	326
September	288	302	345
October	268	276	368
November	276	293	327
December	309	301	319
Annual Average	277	300	314
Range** (Min-Max)	236-429	256-414	224-489

*The discharge from Blue Plains in the 1977-1979 period was from "002" located in the Oxon Cove Embayment. According to Blue Plains personnel, this was the only discharge point during that time.

**"Range" represents the lowest mean daily and highest mean daily discharge for the calendar year as reported in the Blue Plains discharge monitoring reports.

Source: D.C. DES, 1977, 1978, 1979

TABLE 8-5. MEAN ANNUAL STP FLOWS, 1977-1979 (after Thomann and Fitzpatrick, 1982)

Treatment Plant	Average Flow in mgd*		
	1977	1978	1979
Arlington	19.6	22.6	22.8
Alexandria	19.4	29.2	27.3
Piscataway	11.9	16.8	17.5
Lower Potomac	14.0	16.7	21.3
Hunting Creek	4.1	5.1	5.4
Dale City	2.4	2.4	1.4
Westgate	10.8	4.2	8.0
Dogue Creek	2.3	2.6	3.0
Blue Plains	277	300	314

*1 mgd = 1.547 cfs

Source: Individual Plant Discharge Monitoring Reports and L.J. Clark, 1977, 1978, and 1979.

Non-Point Inflows--

The Potomac Estuary receives discharges from a series of tributaries, some of which are gaged by the USGS. However, the gaged flows are not adequate to model tributary inflows because approximately half of the tributaries are not gaged, and some of those which are gaged do not have the gages located near to their junctions with the estuary. In order to overcome this problem, Thomann and Fitzpatrick (1982) during the Hydroqual study developed a simple method of estimating missing flow data on the basis of those that were available. Tributary flows where the gage was not close to the estuary were estimated by multiplying the gaged flow by the ratio of the total watershed area to the area upstream of the gage. Tributary flows in ungaged tributaries were estimated by multiplying flows in adjacent tributaries by the ratios of the tributary watershed areas. The watersheds of tributaries to the upper Potomac Estuary are shown in Figure 8-4, and their areas are given in Table 8-6. The Hydroqual methods for estimating tributary flows are summarized in Table 8-7. The gaged tributary flows which are used in these calculations must be retrieved from STORET using the USGS station numbers given in Table 8-7. The Hydroqual analysis is confined to those tributaries above Sandy Point because it was judged that the tributaries further downstream could reasonably be neglected. These lower tributaries are mostly small, and the significance of their flows and loads is reduced because the lower section of the estuary has such a high volume.

The cities of Washington, DC and Alexandria have combined sewers which overflow to the Potomac and Anacostia Rivers. The Washington CSO's can be divided into two broad categories: those that discharge into the Potomac River between 4.5 km (2.8 mi) and 7.7 km (4.8 mi) downstream from Chain Bridge, and those which discharge into the Anacostia River. Most of the Alexandria CSO's discharge to the Potomac between 16.0 km (9.97 mi) and 19.5 km (12.13 mi) downstream from Chain Bridge. However, some of the Alexandria CSO's drain to the Hunting Creek embayment.

O'Brien and Gere estimated CSO flows by calibrating the Storm Water Management Model (SWMM) to calculate flow rates from rainfall hyetographs. Table 8-8 gives estimates of monthly CSO flows for 1966 through 1970. O'Brien and Gere Inc. have also supplied information on CSO flows and loads for selected storms in 1979 and 1980, and this bulky information is contained in an addendum to this report. Aggregated loading rates for two of these storms are also given in the form of DEM input data in the computer data set.

8-8-3. Hydraulic Data

Estuary Geometry--

Jaworski and Clark (undated) present physical data for the Potomac Estuary and the Anacostia River. These data were determined for the Thomann mathematical model of the estuary (Pence et al., 1968) which uses physical data under "average" tidal conditions. Originally the Thomann model divided the Potomac into 28 segments, but it was later revised to break the estuary into 73 segments. The Thomann model breaks the tidal

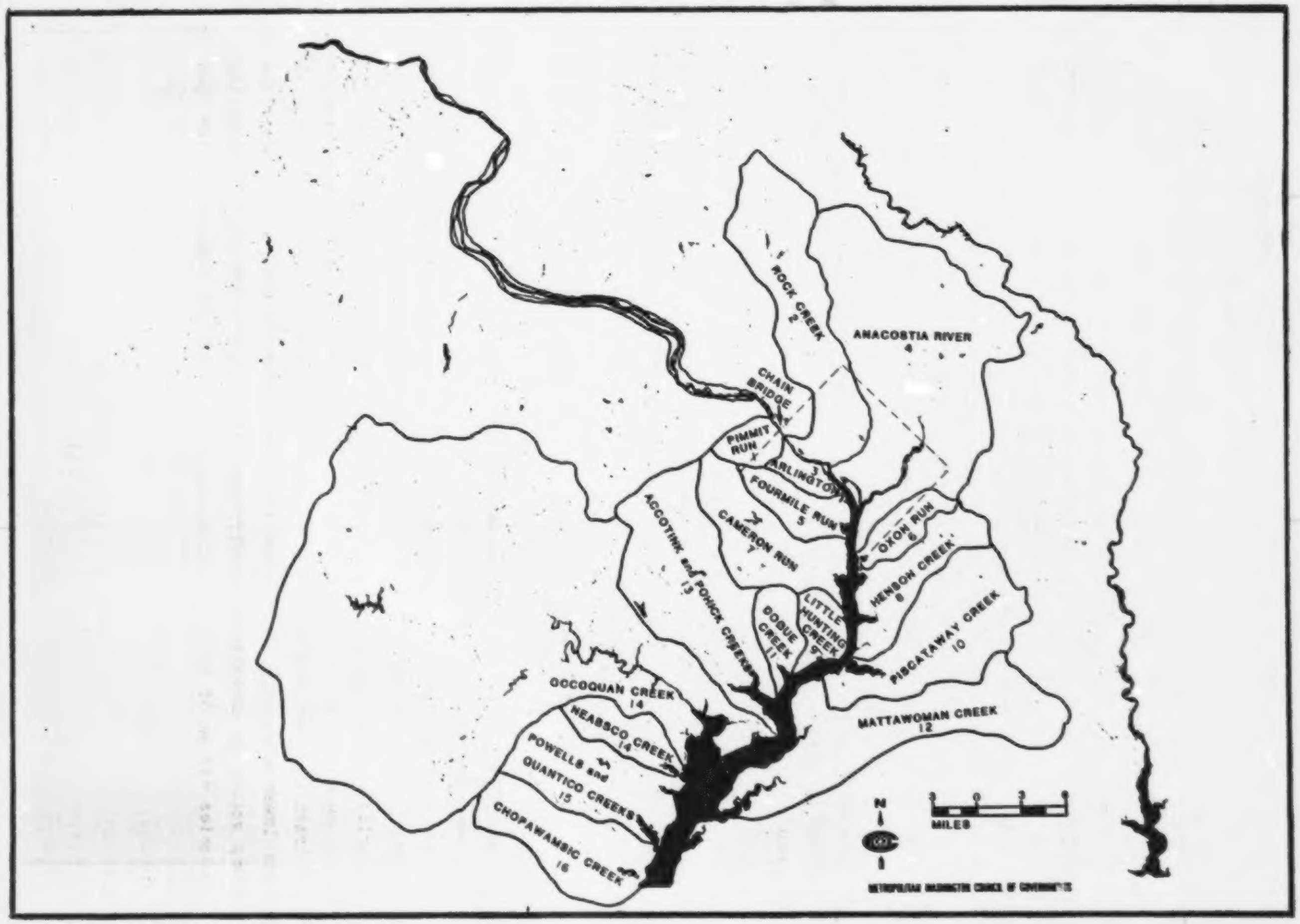
ROCK CREEK
2
ANACOSTIA RIVER
4
CHAIN BRIDGE
PIMMIT RUN
1
ARLINGTON
3
FOURMILE RUN
5
OXON RUN
6
CAMERON RUN
7
HENSON CREEK
8
LITTLE HUNTING CREEK
9
PISCATAWAY CREEK
10
DOGUE CREEK
11
MATTAWOMAN CREEK
12
ACCOTINK and POHICK CREEKS
13
OCCOQUAN CREEK
14
NEABSCO CREEK
14
POWELLS and QUANTICO CREEKS
15
CHOPAWAMSIC CREEK
16
N
MILES
METROPOLITAN WASHINGTON COUNCIL OF GOVERNMENTS

Figure 8-4. Tributary watersheds of the upper Potomac Estuary (after Thomann and Fitzpatrick, 1982).

TABLE 8-6. TRIBUTARIES CONTRIBUTING NONPOINT LOADS TO UPPER POTOMAC ESTUARY (after Thomann and Fitzpatrick, 1982)

Tributary No.*	Name	Area (mi^2)	Area (km^2)
1	Pimmit Run	11.8	30.6
2	Rock Creek	78.3	202.8
3	Arlington-Direct Potomac Drainage	12.4	32.1
4	Anacostia River	175.0	453.2
5	Four Mile Run	17.4	45.1
6	Oxon Run	17.0	44.0
7	Cameron Run	54.6	141.4
8	Henson Creek	35.9	93.0
9	Little Hunting Creek	10.5	27.2
10	Piscataway Creek	67.6	175.1
11	Dogue Creek	18.2	47.1
12	Mattawoman Creek	70.3	182.1
13	Accotink and Pohick Creeks	92.1	238.5
14	Occoquan and Neabsco Creeks	628.3	1627.3
15	Powell's and Quantico Creeks	59.1	153.1
16	Chopawamsic Creek	31.3	81.1

*Corresponds to tributary number on map of tributaries.

TABLE 8-7. BASIS FOR ESTIMATION OF DISCHARGES BY TRIBUTARIES (after Thomann and Fitzpatrick, 1982)

Tributary No.	Description of Estimation
1	Pimmit Run - Q was estimated by applying a ratio 0.2 to gaged Q in Rock Creek (GS-01648000).
2	Rock Creek - Q was estimated by applying a ratio of 1.26 to gaged Q in Rock Creek (GS-01648000).
3	Arlington Direct Drainage - Q was estimated by applying a ratio of 0.9 to gaged Q in Four Mile Run (GS-01652500) for 1966 and 1968, and a ratio of 0.37 to gaged Q in Cameron Run (GS-01653000) for 1969, 1970, 1977, 1978, and 1979.
4	Anacostia River - Q was estimated by applying a ratio of 1.4 to the combined gaged Q of the Northwest Branch (GA-01651000) and the Northeast Branch (GS-01649500) of the Anacostia.
5	Four Mile Run - Q was estimated by applying a ratio of 1.26 to gaged Q in Four Mile Run (GS-01652500) for 1966 and 1968, and by applying a ratio of 0.52 to gaged Q in Cameron Run (GS-01653000) for 1969, 1970, 1977, 1978, and 1979.
6	Oxon Run - Q was estimated by applying a ratio of 1.0 to gaged Q in Henson Creek (GS-01653500) for all years but 1979 when a ration of 0.43 was applied to gaged Q in Piscataway Creek (GS-01653000).
7	Cameron Run - Q was estimated by applying a ratio of 1.62 to gaged Q in Cameron Run (GS-01653000).
8	Henson Creek - Q was estimated by applying a ratio of 2.15 to gaged Q in Henson Creek (GS-01653500) except for 1979 when a ratio of 0.91 was applied to gaged Q in Piscataway Creek (GS-01653600).
9	Little Hunting Creek - Q was estimated by applying a ratio of 0.31 to gaged Q in Cameron Run (GS-01653000).
10	Piscataway Creek - Q was estimated by applying a ratio of 1.71 to gaged Q in Piscataway Creek (GS-01653600) except for 1966 when a ratio of 1.88 was applied to gaged Q in Henson Creek (GS-01653500).

(Continued)

TABLE 8-7. (Concluded)

Tributary No.	Description of Estimation
11	Dogue Creek - Q was estimated by applying a ratio of 0.54 to gaged Q in Cameron Run (GS-01653000).
12	Mattawoman Creek - Q was estimated by applying a ratio of 1.2 to gaged Q in Mattawoman Creek (GS-0165800) for 1966, 1968, 1969, and 1970, and by applying a ratio of 1.8 to gaged Q in Piscataway (GS-01653600) for 1977, 1978, and 1979.
13	A combined estimate of Q for both Accotink and Pohick Creeks was made by applying a ratio of 2.3 to gaged Q in Accotink Creek (GS-01654000).
14	A combined estimate of Q for Neabsco Creek and the Occoquan Creek and local drainage below the Occoquan Reservoir Dam was made by applying a ratio of 2.5 to gaged Q in Accotink Creek (GS-01654000).
15	A combined estimate of Q for Powell's and Quantico Creeks was made by applying a ratio of 7.0 to gaged Q in the South Fork Quantico Creek (GS-01658500).
16	Choppawamsic Creek Q was estimated by applying a ratio of 4.0 to gaged Q in the South Fork Quantico Creek (GS-01658500).

TABLE 8-8. WASHINGTON, DC, COMBINED SEWER OVERFLOW VOLUMES 1966-1970 (after Thomann and Fitzpatrick, 1982)

	(flows in millions of gallons)							
	1966		1968		1969		1970	
Month	Potomac CSO	Anacostia CSO	Potomac CSO	Anacostia CSO	Potomac CSO	Anacostia CSO	Potomac CSO	Anacostia CSO
January	460	470	229	235	197	201	144	148
February	416	525	93	95	242	248	313	320
March	168	172	426	436	186	190	328	336
April	388	396	178	182	199	204	623	640
May	319	327	492	504	140	143	325	336
June	235	245	862	900	403	418	326	335
July	108	111	152	126	1,099	1,158	945	991
August	194	204	460	478	813	852	127	132
September	800	827	346	359	590	620	183	138
October	550	565	369	381	133	136	239	244
November	175	179	421	431	278	286	672	691
December	382	228	258	264	761	779	388	378
Total Yearly Volume	4,195	4,149	4,286	4,391	5,041	5,235	4,613	4,689
Annual Daily Average (mgd)	11.5	11.4	11.7	12.0	13.8	14.3	12.6	12.8

Source: O'Brien and Gere, Inc. (personal communication) section of the Anacostia River into 15 segments. The model segments are shown in Figures 8-5 and 8-6. Tables 8-9 and 8-10 give the interfacial areas between each segment, and length, volume, surface area, mean width, and mean depth for each segment. Table 8-11 gives surface area, average depth and volume at low and average water, for the embayments of the Potomac Estuary. Graphs of cross section area, accumulative surface area, and accumulative volume, as functions of distance downstream from Chain Bridge are given in Figures 8-7 to 8-9. Thatcher and Harleman (1972a) obtained the best verification for their quantity modelling using a Manning's n value of 0.018.

Additional bathymetric data may be obtained from the NOAA National Ocean Survey Nautical Chart 12285, "Potomac River - District of Columbia, Maryland, Virginia."

Dispersion Coefficients--

Definitive measurements of dispersion coefficients are presented by Hetling and O'Connell (1966). These values have been applied in several studies. Variation of the longitudinal dispersion coefficient with salinity gradients is described by Thatcher and Harleman (1972a, 1972b). An average dispersion coefficient of 110 ft^2/sec (10.2 m^2/sec) is reported by Najarian and Harleman (1975) for the non-saline upper reaches of the Potomac.

Tide Data--

Tidal variations are given for locations along the Potomac in the "Tide Tables" published for each year by the National Ocean Survey, including for Piney Point on Chesapeake Bay (mean tidal range approximately 1.4 ft or 0.43 m) and for Washington, DC (mean tidal range approximately 2.9 ft or 0.88 m). Thatcher and Harleman (1972a) point out that use of Tide Table data is difficult because of lack of information on the datum used at each station. However, tidal ranges may readily be deduced. The tidal period is approximately 12.4 hours.

8-3-4. Climatological Data

Climatological data for the areas surrounding the Potomac Estuary may be obtained from the NOAA publications of climatological data for the areas surrounding the Potomac. Precipitation is necessary for making estimates of CSO's from Washington, DC and Alexandria, but is not required for estimation of tributary flows, and the judgement of the Hydroqual report (Thomann and Fitzpatrick, 1982) is that direct precipitation into the estuary is not a significant input. Wind speed is required for estimation of reaeration coefficients, and solar insolation is necessary for modelling algal growth. The USGS Potomac data reports for 1980 and 1981 present insolation measurements made during the USGS water quality surveys.

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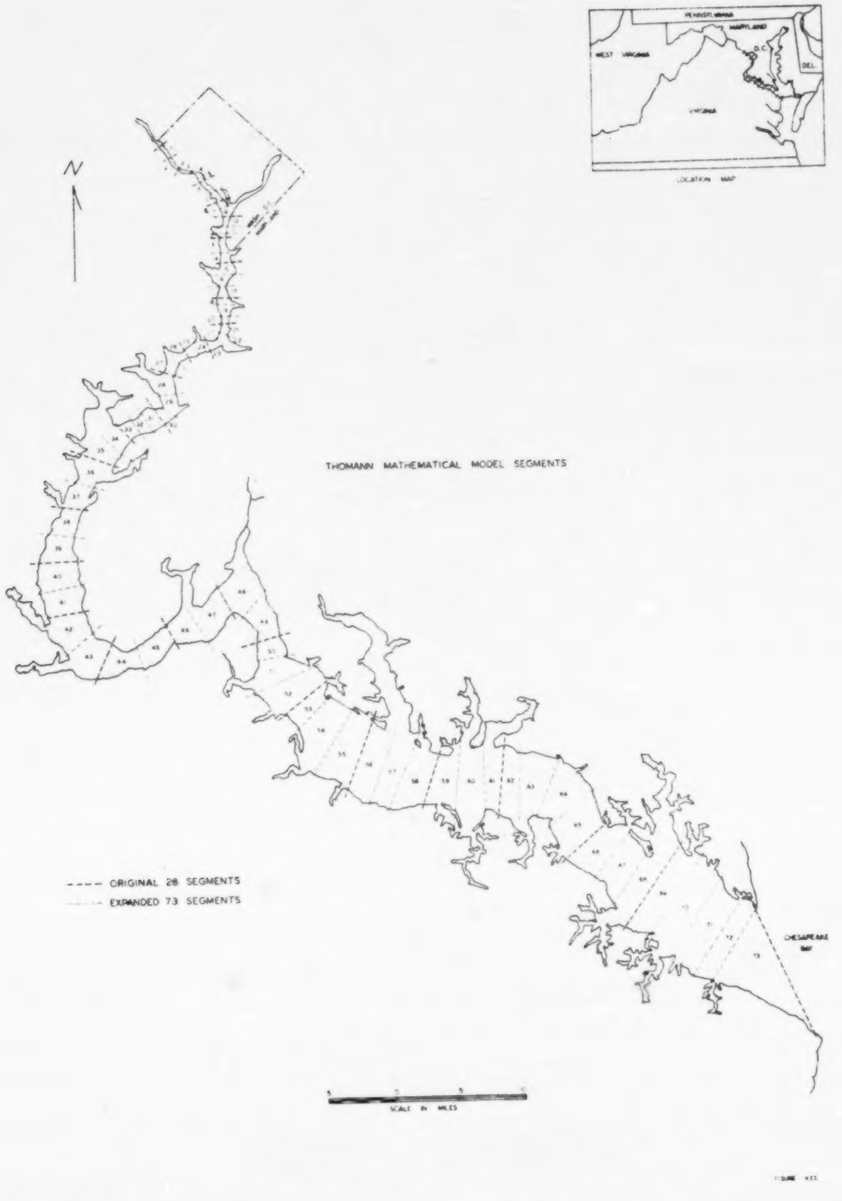
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THOMANN MATHEMATICAL MODEL SEGMENTS
ORIGINAL 28 SEGMENTS
EXPANDED 73 SEGMENTS
CHESAPEAKE BAY
SCALE IN MILES
FIGURE 8-5

Figure 8-5. Thomann model segments of the Potomac Estuary (after Jaworski and Clark, undated).

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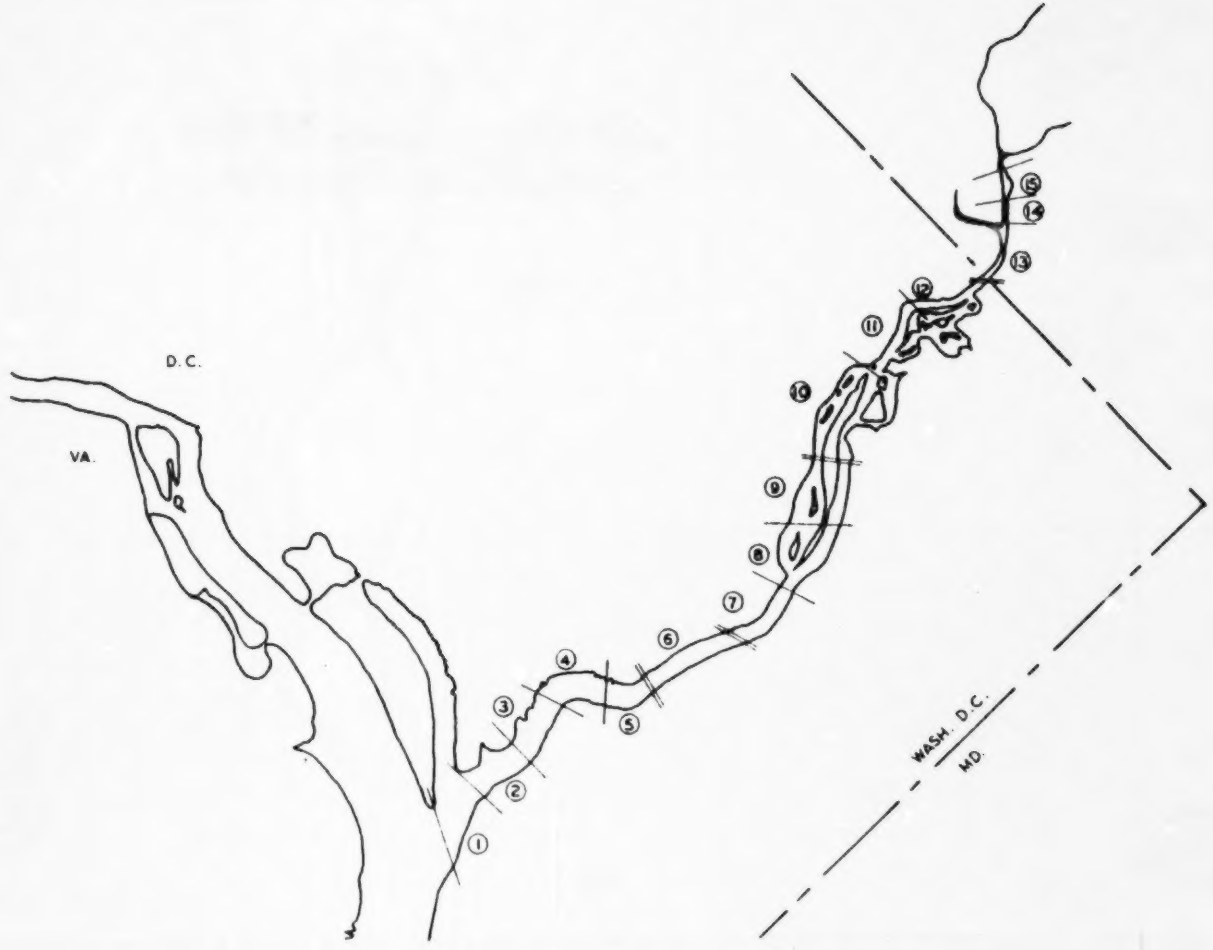
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Figure 8-6. Thomann model segments of the tidal section of Anacostia River (after Jaworski and Clark, undated).

TABLE 8-9. THOMANN MODEL POTOMAC ESTUARY GEOMETRY FOR MEAN WATER DATA (Excluding Embayments) (after Jaworski and Clark, undated)

Segment Number	Interface Areas Upper (ft^2)	Interface Areas Lower (ft^2)	Length (ft)	Volume ($ft^3 \times 10^8$)	Surface Area ($ft^2 \times 10^6$)	Width (ft)	Depth (ft)
1	1078	6630	7814	0.30	3.222	412	9.3
2	6630	42960	7076	1.75	5.110	722	34.2
3	42960	22282	2851	0.93	3.110	1091	29.9
4	22282	23406	4065	0.93	4.560	1122	20.4
5	23406	25062	3749	0.91	6.110	1630	14.9
6	25062	21789	5597	1.31	10.766	1925	12.2
7	21789	24153	3590	0.82	8.443	2352	9.7
8	24153	28676	5439	1.44	15.108	2778	9.5
9	28676	34815	4065	1.29	10.331	2541	12.5
10	34815	43352	1690	0.66	5.110	3024	12.9
11	43352	36996	3696	1.48	10.331	2795	14.3
12	36996	40740	3010	1.17	8.998	2989	13.0
13	40740	32160	6124	2.23	16.663	2721	13.4
14	32160	37860	5280	1.85	14.219	2693	13.0
15	37860	33255	3960	1.41	11.331	2861	12.4
16	33255	57396	3855	1.75	13.775	3573	12.7
17	57396	50760	6177	3.34	25.106	4064	13.3
18	50760	56172	2640	1.41	13.886	5260	10.2
19	56172	58875	5386	3.10	23.106	4290	13.4
20	58875	53588	3274	1.84	10.776	3291	17.1
21	53588	58992	5280	2.97	14.997	2840	19.8

(Continued)

TABLE 8-9. (Continued)

Segment Number	Interface Areas Upper (ft^2)	Interface Areas Lower (ft^2)	Length (ft)	Volume ($ft^3 \times 10^8$)	Surface Area ($ft^2 \times 10^6$)	Width (ft)	Depth (ft)
22	58992	87642	3009	2.21	9.220	3064	24.0
23	87642	66372	5227	4.03	21.551	4123	18.7
24	66372	84210	5069	3.82	29.439	5808	13.0
25	84210	64654	5016	3.73	27.994	5581	13.3
26	64654	72693	4805	3.30	19.996	4162	16.5
27	72693	92850	8765	7.25	35.882	4094	20.2
28	92850	97380	9031	8.64	53.656	5909	16.1
29	97380	116509	6706	7.17	42.436	6328	16.9
30	116509	108537	8342	9.39	50.768	6986	18.5
31	108537	129910	5597	6.67	53.767	9606	12.4
32	129910	128000	5650	7.29	38.659	6842	18.9
33	128000	130350	4065	5.25	30.883	7597	12.0
34	130350	136980	6706	8.96	76.429	11397	11.7
35	136980	191700	8026	13.19	105.757	13177	12.5
36	191700	181894	10507	19.63	100.535	9569	19.5
37	181894	165915	13464	23.41	94.981	7054	24.6
38	165915	191334	9715	17.35	88.648	9125	19.5
39	191334	218520	12144	24.87	147.414	12139	16.8
40	218250	246360	10876	25.27	190.184	17486	13.3
41	246360	221328	11246	26.30	187.740	16427	14.2
42	221328	216642	12460	27.29	178.630	14336	15.3

(Continued)

TABLE 8-9. (Continued)

Segment Number	Interface Areas		Length (ft)	Volume ($ft^3 \times 10^8$)	Surface Area ($ft^2 \times 10^6$)	Width (ft)	Depth (ft)
	Upper (ft^2)	Lower (ft^2)					
43	216642	224190	12830	28.28	212.735	16581	13.3
44	224190	172892	10824	21.50	126.308	11669	17.0
45	172892	165060	17529	29.60	124.752	7117	23.7
46	165060	214518	10560	20.04	130.196	12330	15.4
47	214518	205614	14256	29.95	197.071	13824	15.2
48	205614	236645	12936	28.61	164.189	12685	17.4
49	236645	248468	12038	29.20	122.197	10151	23.9
50	248468	258192	9820	24.88	107.200	10916	23.2
51	258192	444206	6441	22.62	190.184	29526	11.9
52	444206	483595	10560	48.99	261.392	24753	18.7
53	483595	328522	9451	38.38	164.411	17396	23.3
54	328522	548750	6811	29.88	337.154	49501	8.9
55	548750	574886	10665	59.92	333.711	31290	18.0
56	574886	690598	10137	64.14	316.381	31210	20.3
57	690598	640497	8712	57.98	256.948	29494	22.6
58	640497	508966	13203	70.70	373.591	30368	18.9
59	508966	550744	10612	56.23	264.947	24967	21.2
60	550744	608974	11616	67.36	314.937	27113	21.4
61	608974	607517	6705	40.78	312.159	46556	13.1
62	607517	616704	8712	53.33	233.953	26854	22.8
63	616704	644292	8659	54.59	288.831	33356	18.9

(Continued)

TABLE 8-9. (Concluded)

Segment Number	Interface Areas Upper (ft^2)	Lower (ft^2)	Length (ft)	Volume ($ft^3 \times 10^8$)	Surface Area ($ft^2 \times 10^6$)	Width (ft)	Depth (ft)
64	644292	724601	8659	59.27	270.834	31277	21.9
65	724601	746890	16104	118.48	345.819	21474	34.3
66	746890	858496	10560	84.66	262.058	24816	32.3
67	858496	857947	10348	88.81	257.615	24896	34.5
68	857947	1156690	10507	105.84	323.713	30809	32.7
69	1156690	1144810	11352	130.63	421.026	37087	31.0
70	1144810	1182700	10560	122.89	403.030	36166	30.5
71	1182720	1162709	11140	130.64	367.704	32992	35.5
72	1162709	1198613	8448	99.74	310.604	36766	32.1
73	1198613	1724765	9662	141.23	766.291	79309	18.4

TABLE 8-10. THOMANN MODEL TIDAL ANACOSTIA RIVER GEOMETRY FOR MEAN WATER DATA* (after Jaworski and Clark, undated)

Segment Number	Interface Areas Upper (ft^2)	 Lower (ft^2)	Interface Widths Upper (ft)	 Lower (ft)	Length (ft)	Volume ($ft^3 x10^6$)	Surface Area ($ft^2 x10^6$)	Depth (ft)
1	31,290	58,060	1500	3200	2900	129.55	4.96	26.11
2	27,100	31,290	1250	1500	2380	69.48	3.24	21.44
3	27,100	27,100	1250	1250	2380	64.49	2.68	24.06
4	24,710	27,100	1150	1250	2040	68.38	3.20	21.36
5	14,450	24,710	750	1150	2640	51.69	2.36	21.90
6	8,580	14,450	750	750	3430	39.84	2.80	14.22
7	8,645	8,580	750	750	3430	29.53	2.44	12.10
8	3,095	8,645	550	750	3170	18.60	1.76	10.56
9	4,805	3,095	400	550	2900	11.45	1.36	8.41
10	2,840	4,805	350	400	3960	15.13	1.32	11.46
11	3,195	2,840	300	350	3170	9.56	1.00	9.56
12	3,000	3,195	300	300	3430	10.62	1.04	10.21
13	3,050	3,000	250	300	2900	8.74	0.80	10.92
14	1,775	3,030	250	250	2640	6.34	0.60	10.57
15	775	1,775	200	250	2640	5.20**	1.00	5.20

*Data based on soundings made April 1970

**Volume of Marina = 1500 ft x 2710 ft^2 = 4.06 x 10^6 ft^3

TABLE 8-11. THOMANN MODEL POTOMAC ESTUARY EMBAYMENT GEOMETRY FOR MEAN AND LOW WATER DATA (after Jaworski and Clark, undated)

Name	Segment	Surface Area ($ft^2 x10^6$)	Average Depth at Low Water (ft)	Volume at Low Water ($ft^3 x10^8$)	Average Depth at Mean Water (ft)	Volume at Mean Water ($ft^3 x10^8$)	Location (Miles below Chain Bridge)
Columbia Island Channel	3	2.555	5.0	0.13	6.40	0.16	4.65 - 5.76
Tidal Basin	3	4.444	9.0	0.40	10.40	0.46	5.81
Washington Channel	4	8.109	23.0	1.86	24.45	1.98	-
Anacostia River	4	35.993	14.0	5.04	15.45	5.56	7.60 - 8.20
Four Mile (Hunter Pt.)	5	6.332	11.0	0.70	12.45	0.79	8.79 - 9.70
Oxon Creek (Upper)	6	13.664	8.0	1.09	9.40	1.28	10.55 - 12.13
Oxon Creek (Lower)	7	18.330	8.0	1.45	9.35	1.71	12.13 - 13.57
Hunting Creek	7	21.218	2.0	0.42	3.35	0.71	12.13 - 13.50
Broad Creek	8	16.219	3.0	0.49	4.30	0.70	14.90 - 15.92
Piscataway Creek	9	36.437	3.0	1.09	4.20	1.53	18.11 - 18.63
Little Hunting Creek	10	4.444	2.0	0.09	3.10	0.14	19.90 - 20.33
Douge Creek	11	17.885	3.0	0.54	4.05	0.72	21.85 - 22.80
Gunston Cove	12	65.431	4.0	2.62	5.00	3.27	24.02 - 25.42
Pomonkey Creek	12	8.776	3.0	0.26	3.95	0.35	26.73 - 27.10

(Continued)

TABLE 8-11. (Continued)

Name	Segment	Surface Area ($ft^2 x10^6$)	Average Depth at Low Water (ft)	Volume at Low Water ($ft^3 x10^8$)	Average Depth at Mean Water (ft)	Volume at Mean Water ($ft^3 x10^8$)	Location (Miles below Chain Bridge)
Belmont Bay	14	69.431	4.0	2.78	4.80	3.33	-
Occoquan Bay	14	148.859	5.0	7.44	5.80	8.63	31.45 - 34.09
Powells Creek	15	19.218	2.0	0.38	2.80	0.54	34.79 - 35.92
Mattawoman Creek	15	74.541	8.0	5.96	8.80	6.56	34.13 - 35.60
Quantico Creek	15	29.327	2.0	0.59	2.70	0.79	38.10 - 38.55
Chicamuxen Creek	15	22.773	3.0	0.68	3.70	0.84	36.91 - 37.75
Chopawamsic Creek	16	13.553	2.0	0.27	2.67	0.36	40.75
Mallows Bay	16	4.444	4.0	0.18	4.65	0.21	41.64 - 42.44
Aquia Creek	18	101.091	4.0	4.04	4.60	4.65	46.89 - 48.40
Potomac Creek	18	76.985	3.0	2.31	3.58	2.76	49.20 - 49.70
Nanjemoy Creek	20	124.975	3.0	3.75	3.55	4.44	58.18 - 59.20
Port Tobacco River	21	163.856	6.0	9.83	6.75	11.06	62.00 - 63.80
Upper Machodoc Creek	22	1.736	5.0	3.59	5.80	4.16	69.45 - 71.32
Rosier Creek	22	14.442	3.0	0.43	3.80	0.55	72.60 - 73.27
Cuckold Creek	23	16.663	2.0	0.33	2.80	0.47	72.00 - 72.21

(Continued)

TABLE 8-11. (Concluded)

Name	Segment	Surface Area ($ft^2 x10^6$)	Average Depth at Low Water (ft)	Volume at Low Water ($ft^3 x10^8$)	Average Depth at Mean Water (ft)	Volume at Mean Water ($ft^3 x10^8$)	Location (Miles below Chain Bridge)
Monroe Creek	23	18.552	3.0	0.56	3.80	0.70	-
Mattox Creek	23	61.988	5.0	3.10	5.80	3.60	75.98 - 77.32
Popes Creek	23	12.442	1.0	0.12	1.85	0.23	79.15
Wicomico River	24	389.367	9.0	35.04	9.92	38.62	80.52 - 82.85
St. Clement Bay	25	154.080	9.0	13.87	9.90	15.25	86.05 - 88.35
Breton Bay	25	135.306	9.0	12.18	9.90	13.40	89.36 - 90.20
Nomini Bay	25	126.086	6.0	7.56	6.80	8.57	87.26 - 89.48
Lower Machodoc Creek	26	92.648	7.0	6.48	7.85	7.27	91.15 - 93.38
Herring Creek	26	18.330	4.0	0.73	4.80	0.88	96.10
St. Georges Creek	27	77.318	5.0	3.87	5.75	4.45	-
St. Mary's River	27	285.165	11.0	31.37	11.75	33.51	102.96 -104.35
Yeocomico River	27	141.638	6.0	8.50	6.63	9.39	103.80 -104.65
Smith Creek	28	48.657	7.0	3.40	7.75	3.77	105.15 -106.65
Coan River	28	100.424	6.0	6.02	6.60	6.63	107.20 -109.00
Hull Creek	28	20.329	6.0	1.22	6.60	1.34	113.00

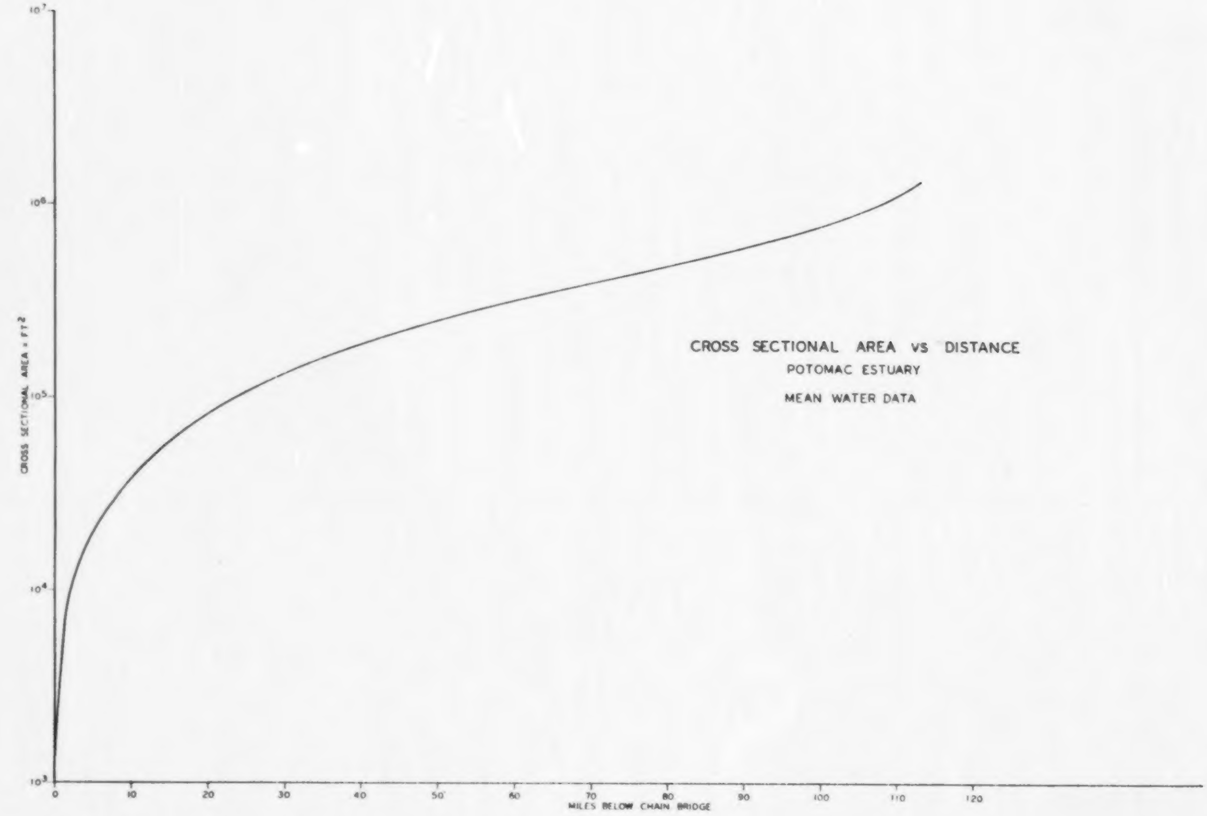

Figure 8-7. Estuary cross sectional area as a function of distance from Chain Bridge (after Jaworski and Clark, undated).

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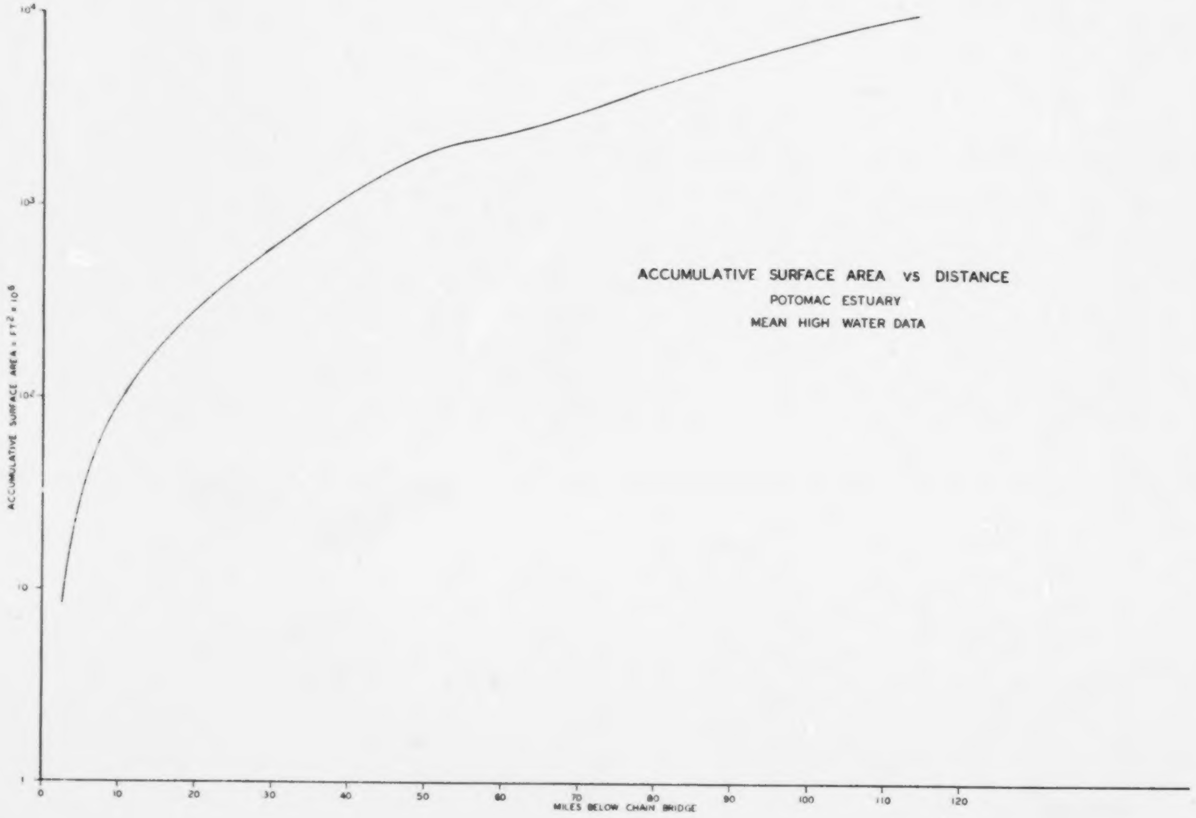

Figure 8-8. Estuary surface area as a function of distance from Chain Bridge (after Jaworski and Clark, undated).

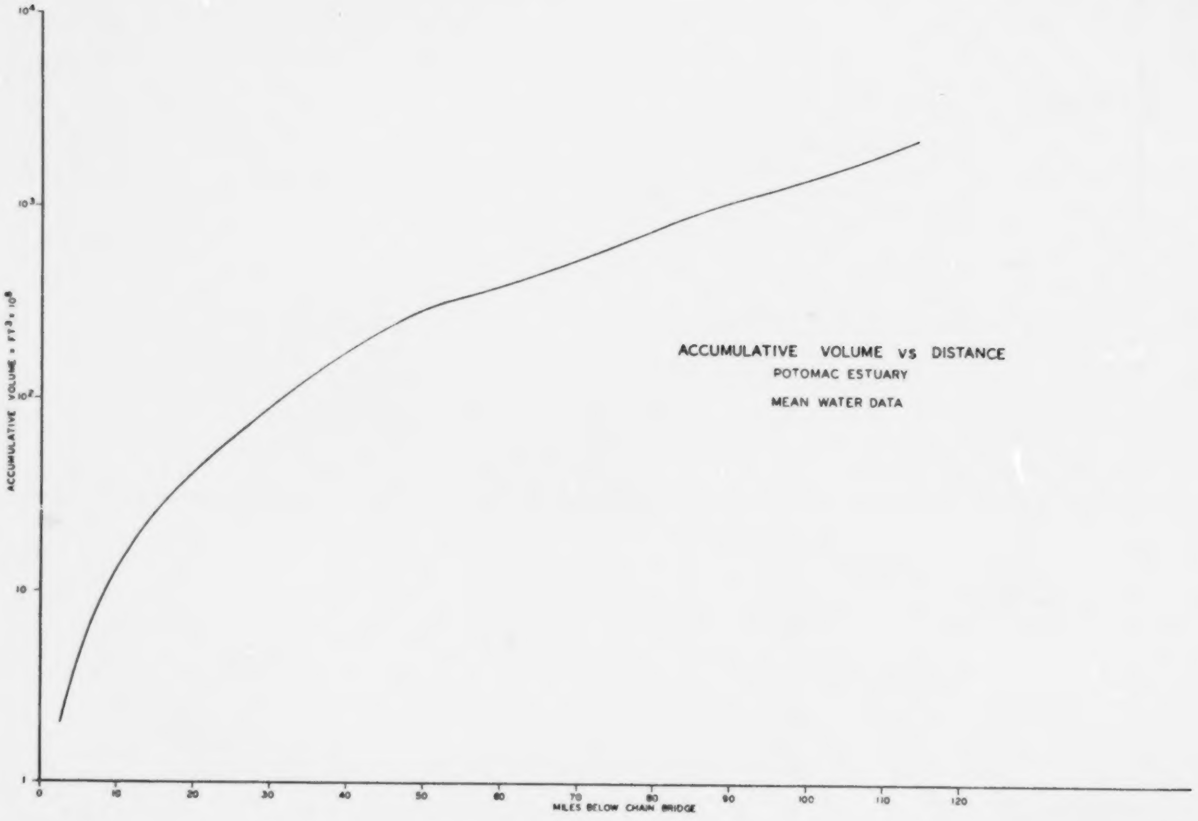

Figure 8-9. Estuary volume as a function of distance from Chain Bridge (after Jaworski and Clark, undated).

8-3-5. Sampling Data Sources

Flow Rates--

The USGS gages flow in the Potomac River at Little Falls, and also gages about half of the tributaries which discharge into the Potomac Estuary. These flows can be retrieved from STORET. The computer data set includes Potomac flow data, but does not contain measurements of tributary flows.

The addendum and the computer data set also include some information on CSO flows in 1979 and 1980, and STP discharge rates in 1977, 1978, 1979 and 1980. The data set contains measurements made during intensive studies in those years, not continuous records. The CSO discharges are calculated from urban rainfall using the SWMM program, and measurements of STP discharges are intermittent. The CSO discharges were calculated by O'Brien and Gere, while most STP flows were measured by either the USGS or the EPA.

Climatological Data--

Climatological data for the areas surrounding the Potomac Estuary are published by NOAA. Additional data may be available from other agencies.

8-4. ESTUARY QUALITY DESCRIPTION

8-4-1. Major Pollution Sources

Point Sources--

Inflow to the study area at Chain Bridge from the headwaters may be considered as a point source. The part of the watershed upstream of this point is largely agricultural or forested, but there is also quite a large number of small STP's which discharge into the upper Potomac River. The USGS maintains a river quality monitor at Chain Bridge (station number 01646580), and water quality data from this station may be retrieved from STORET. Loads may then be calculated by multiplying concentrations by the flow rate.

The other principal point sources to the estuary are the STP's which were described in Section 8-3-2. Their positions are given in Figure 8-2 and Table 8-2. The Blue Plains STP contributes 75% to 80% of the total STP discharges to the river, and it also provides a greater nutrient load than all the other STP's combined. STP loads during the late 1960's and early 1970's are not well defined, but data during the late 1970's are much more complete. Information on Blue Plains STP flows, BOD, and nutrient loads to the Potomac is presented in Table 8-12 and Figure 8-10, while flow and loading data from the other STP's are presented in Tables 8-13 and 8-14.

The computer data set contains some Blue Plains effluent quality data measured by the EPA in 1968, and a detailed study of STP discharge

TABLE 8-12. BLUE PLAINS BOD_5 AND NUTRIENT LOADING DATA, 1968-70
(after Thomann and Fitzpatrick, 1982)

Year	Date	Flow mgd	BOD_5 lbs/day	Total P lbs P/day	Inorganic P lbs P/day	TKN lbs N/day	NH_3 lbs N/day	NO_3 lbs N/day
1968	8/19-22	261	92,000	14,300	NR	40,000	20,000	NR
1969	8/11-15	273	94,000	16,600	NR	37,000	29,000	1,450
	11/3-5	251	NR	20,800	15,600	75,000	40,600	14
1960	NR	251.66	103,800	17,300	NR	46,200	NR	2,000

NR = Not Recorded

Sources of Data: 1968 - FWPCA, 1969
1969 - FWPCA, 1969b and EPA, 1969
1970 - Jaworski, 1971

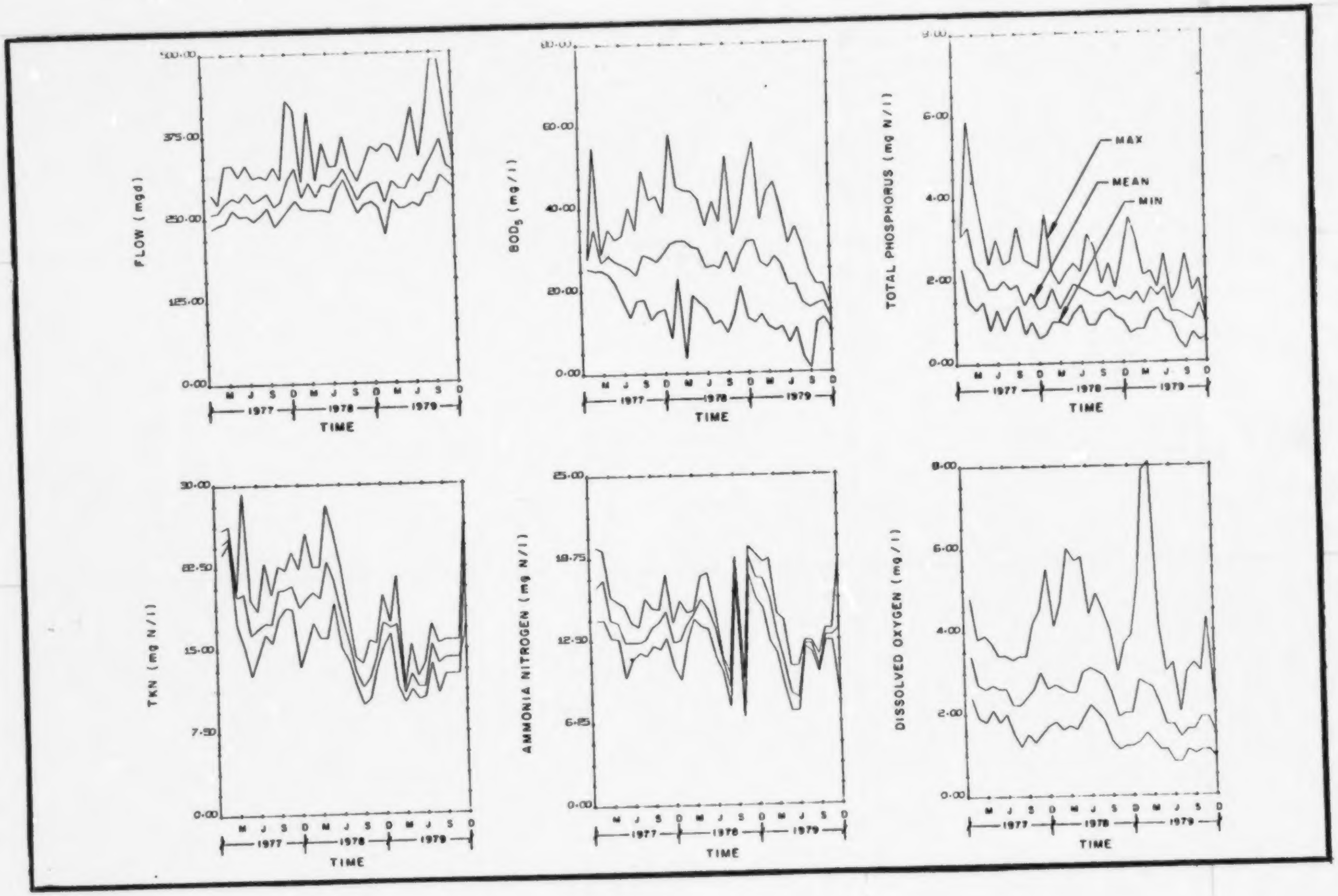

Figure 8-10. Blue Plains effluent flows and concentrations, 1977-1979 (after Thomann and Fitzpatrick, 1982).

TABLE 8-13. STP EFFLUENT FLOWS AND LOADS, 1968-1970 (after Thomann and Fitzpatrick, 1982)

Treatment Plant	Survey Date	Flow mgd	BOD_5 lbs/day	Total P lbs/day	Inorg P lbs/day	TKN lbs/day	NH_3 lbs/day	NO_2+NO_3 lbs/day
Alexandria	8/19-22/68	19.8	8,300	1,500	NR	3,600	2,300	NR
	8/11-15/69	23.6	11,300	1,540	NR	3,370	2,320	50
	11/2-4/69	18.3	NR	2,340	1,570	3,700*	3,900*	<2
	Summer 70	23.3	13,000	2,300	NR	3,690	NR	20
Arlington	1966	NR	NR	NR	NR	NR	3,900	483
	1968-70	NR	NR	NR	NR	NR	2,300	(Sum)966 (Win)483
	8/19-22/68	21.3	4,100	1,700	NR	3,400	2,100	NR
	8/11-15/69	19.3	5,400	990	NR	3,030	2,220	920
	11/3-5/69	17.6	NR	1,500*	1,650*	1,300*	1,700*	5,600#
Fairfax-Dogue	8/19-22/68	1.36	430	150	NR	260	160	NR
	8/11-15/69	2.23	800	180	NR	280	230	40
	Summer 70	2.441	915	270	NR	365	NR	20
Fairfax-Hunting	8/19-22/68	2.87	820	300	NR	640	310	NR
	8/11-15/69	3.35	1,500	270	NR	550	430	25
	Summer 70	3.26	1,390	380	NR	620	NR	15
Fairfax-Westgate	8/19-22/68	11.28	14,500	980	NR	2,500	1,100	NR
	8/11-16/69	11.83	12,200	960	NR	2,540	1,480	50
	Summer 70	11.57	10,900	1,280	NR	1,830	NR	40
Piscataway	8/19-22/68	5.00	540	300	NR	600	440	NR
	8/11-15/69	7.26	350	160	NR	240	200	390
	Summer 70	5.81	540	320	NR	630	NR	100

*Apparent measurement problem or typographical error in data source as total is greater than component.

#Questionable report

NR = Not Reported

Sources of Data: 1966-70 Arlington STP only, July 1981
1968 FWPCA, 1969a
1969 FWPCA, 1969b and EPA, 1969
1970 Jaworski

TABLE 8-14. STP EFFLUENT FLOWS AND LOADS, 1977-1979 (after Thomann and Fitzpatrick, 1982)

Treatment Plant	Flow mgd	BOD_5 lbs/day	Total P lbs/day	TKN lbs/day	NH_3 lbs/day	NO_2+NO_3 lbs/day	Data Sources Used
1977							
Alexandria	19.39	7,975	1,029	3,281	3,001	16	Clark & Roesch, 1978
Arlington	19.56	1,435	800	2,429	2,218	696	"
Dale City	2.39	234	45	470E	352E	120#	DMR (3) and Clark & Roesch, 1978
Fairfax-Dogue	2.26	210	5	411	375	29	"
Fairfax-Hunting	4.09	447	9	720	672	64	"
Fairfax-Westgate	10.77	1,141	401	1,698	1,438	2	"
Lower Potomac	14.02	1,846	843	2,551	2,244	219	"
Piscataway	11.91	653	95	596	450	470	"
Total	84.39	13,941	3,227	12,156	10,750	1,616	
1978							
Alexandria	29.2	8,284	268	4,605	4,532	24	DMR (8)/Clark & Roesch (1980)
Arlington	22.6	2,527	603	3,696	3,507	226	DMR (11)/ "
Dale City	2.4	108	6	470	352	120E	DMR (11)/ "
Fairfax-Dogue	2.6	234	6	399	377	24	DMR (9)/ "
Fairfax-Hunting	5.11	427	15	777	734	94	DMR (9)/ "
Fairfax-Westgate	4.20	536	204	606	579	4	DMR (9)/ "
Lower Potomac	16.72	1,283	702	2,762	2,608	181	DMR (9)/ "
Piscataway	16.81	1,122	93	1,529	1,417	730	DMR (12)/ "
Total	99.64	14,521	1,897	14,844	14,106	1,403	

DMR (3) = Discharge Monitoring Report 3 Months

E = Estimated

(Continued)

TABLE 8-14. (Concluded)

Treatment Plant	Flow mgd	BOD_5 lbs/day	Total P lbs/day	TKN lbs/day	NH_3 lbs/day	NO_2+NO_3 lbs/day	Data Sources Used
1979							
Alexandria	27.3	5,011	205	4,601	4,396	23	DMR (9)/Roesch, 1981
Arlington	22.8	3,044	590	2,930	2,739	533	DMR (9)/ "
Dale City	3.33	261	16	645E	483E	165E	DMR (11)/ "
Fairfax-Dogue	3.0	523	10	358	340	32	DMR (9)/ "
Fairfax-Hunting	5.42	497	17	696	655	77	DMR (9)/ "
Fairfax-Westgate	8.0	1,122	274	1,001	962	7	DMR (9)/ "
Lower Potomac	21.3	1,511	750	3,448	3,199	89	DMR (9)/ "
Piscataway	17.52	585	91	1,403	1,330	395	DMR (11)/ "
Total	108.67	12,554	1,953	15,082	14,104	1,321	

quality for all STP's during the intensive EPA surveys of 1977 and 1978. The CSO study data from O'Brien and Gere for 1979 and 1980 also include STP loads. These data are described in greater detail in an addendum to this report.

Non-Point Sources--

The largest non-point source of BOD and nutrients is flow from the Potomac Estuary's many tributaries. These tributaries are listed in Table 8-6 and shown in Figure 8-4; a methodology for estimating tributary discharge flow rates is presented in Table 8-7. Unfortunately there have been virtually no nutrient and BOD data measured in the Potomac Estuary tributaries. To make matters worse, the few data that have been measured were mostly taken at infrequent intervals, and are not representative of storm runoff conditions. The only realistic way to estimate tributary loads is by using land use/runoff quality relationships. The Northern Virginia Planning District (1978, 1979, 1980) has published several studies on land use/runoff quality relationships in the Potomac watershed, and Ragan and Dietemann (1976) have studied urban runoff characteristics in Washington, DC.

The other major non-point source of nutrients and BOD is from CSO's. O'Brien and Gere made estimates of CSO discharge flows by using the SWMM model to estimate runoff from storm events. CSO loads for particular events can be estimated by multiplying the estimated flow rates by the nutrient and BOD concentrations measured in the CSO discharges during the storms. O'Brien and Gere Inc. have provided tables of estimated CSO flows and measured nutrient and BOD concentrations for selected storms in 1979 and 1980. CSO loads and water quality in Rock Creek were investigated for two storms in 1979, while CSO loads and water quality for the whole Potomac-Anacostia river system were investigated once in 1979 and twice in 1980. The measured CSO discharge water quality data and calculated CSO discharge flow data are given in an addendum to this report. Aggregated loads from the storms are included in DEM input format in the computer data set, and the river quality data measured during the CSO investigations are also included in the computer data set. Estimates of CSO loads during the intensive EPA Potomac surveys of 1978 are given in Table 8-15, and estimates of total annual loads for a number of years are given in Table 8-16.

Comparison of Point and Non-Point Loads--

The Hydroqual report (Thomann and Fitzpatrick, 1982) presents a comparison of point and non-point loads to the estuary, using the load-estimating techniques described above. This comparison of loads is presented in Table 8-16. In general, the loads from the headwaters and Blue Plains STP are far larger than the loads from other sources.

8-4-2. Biochemical Data

Estuary Quality Sampling--

The Potomac Estuary has been sampled by a large number of agencies. The most extensive studies are by the USGS and the EPA, but there are

TABLE 8-15. ESTIMATED URBAN LOADINGS DURING 1978 INTENSIVE EPA STUDY (after Clark et al., 1980)

Date	Rainfall	Combined Sewers			Storm Sewers		
		BOD_5	TN	TP	BOD_5	TN	TP
	(in)	- - - - - - - - - - - -	- - - - - - - - - - - -	- - - - - - - - - - - -	10^3 lbs - - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -
7/30	0.35	22	2	1	250	26	8
7/31	0.85	57	6	2.5	490	48	18
8/4	0.50	33	3	1	330	34	11
8/5	0.45	30	3	1	300	32	10
8/9	0.30	17	2	1	210	24	6
8/11	0.60	40	4	2	380	38	13
8/13	1.20	77	8	4	610	58	26
8/27	0.35	22	2	1	250	26	8
8/30	2.00	118	12	6.5	810	78	43
9/12	0.55	37	4	1.5	350	36	12
9/22	0.25	13	1	0.5	180	21	5
TOTALS	7.4	466	47	22	4,160	421	160

TABLE 8-16. COMPARISON OF ESTIMATED POINT AND NON-POINT LOADS TO THE POTOMAC ESTUARY (after Thomann and Fitzpatrick, 1982)

(Annual Loads, lbs/day by Source)

Year	Point		Nonpoint Below Chain Bridge	CSO*	Upstream Boundary
	Blue Plains	Other			
CBOD$_5$:					
1966	103,800	32,205	26,456	18,763	109,000
1968	103,800	32,205	24,654	19,249	141,000
1969	103,800	32,205	28,196	21,513	82,000
1970	103,800	32,205	33,994	21,790	196,000
1977	62,606	14,143	14,295	6,903	96,000
1978	74,805	14,521	26,891	7,927	153,000
1979	51,786	12,554	43,732	8,764	220,000
TOTAL P (as P):					
1966	17,301	6,202	712	1,131	2,700
1968	17,301	6,202	673	1,167	3,500
1969	17,301	6,202	805	1,310	2,040
1970	17,301	6,202	931	1,325	4,878
1977	4,563	3,753	371	439	2,864
1978	4,298	1,945	640	516	6,600
1979	3,652	1,964	1,042	565	9,740
TOTAL N:					
1966	37,420	10,308#	7,140	3,439	35,741
1968	37,420	8,894#	6,950	3,510	61,410
1969	37,420	8,846#	7,881	3,966	33,798
1970	37,420	8,916#	9,011	3,879	92,639
1977	45,837	13,968	4,583	990	42,729
1978	46,591	16,248	7,879	1,155	99,242
1979	40,522	16,403	12,985	1,316	151,373

*Includes Georgetown Gap, 1966-1970

#Some variation in Arlington Treatment Plant causes this value to vary between 1966-1970 also smaller data sets measured by other agencies and consulting companies. Most of the USGS and EPA data may be retrieved from STORET, but data from other sources are often only available from reports, and users must enter them into a computer themselves. The station numbers of USGS stations are listed in Table 8-17, and the station positions are shown in Figure 8-11. EPA quality sampling stations are listed in Table 8-18 and shown in Figure 8-12.

The computer data set contains Potomac quality data measured by the USGS in 1977 and 1978, measured by the EPA from 1965 to 1979, measured by the U.S. Army Corps of Engineers in 1977 and 1978, and measured by O'Brien and Gere Inc. in 1979 and 1980. These data are described in greater detail in Section 8-5.

Biochemical Rate Constants--

Thomann and Fitzpatrick (1982) used 75 model runs to calibrate their Potomac Estuary Model using data from 1966 and 1968 to 1970. The model was then verified using data from 1977 to 1979. This model is fully described, and calibration values of the model coefficients and rate constants are given in the Hydroqual report. These data are not presented here because the model is complex, and it is not clear how readily the rate coefficients could be applied to a simpler model. Readers who are interested in this modelling effort are therefore referred to the report.

As discussed earlier, extensive water quality modelling has also been performed by Najarian and Harleman (1975, 1977) who also provide tables of rate constants for nitrogen, phosphorus, algal and DO cycles in the Potomac. The nitrogen cycle formulations presented by Najarian and Taft (1981) were also prepared on the basis of experience in the Potomac. Rate constants used in the DEM studies have been published by Roesch et al. (1979) and Ambrose and Roesch (1982). The studies mentioned in this paragraph are readily available.

8-4-3. Measurement Listing

USGS Data--

The positions of USGS sampling stations are given in Table 8-17 and Figure 8-11. The USGS has conducted investigations of water quality in the Potomac Estuary from 1977 through 1981 (Hammond, 1979; Cole and Alpine, 1980; Blanchard and Hahl, 1981; Blanchard et al., 1982a; Blanchard et al., 1982b). The USGS water quality surveys include a limited amount of STP loading data from the Blue Plains STP, and also river flow data. A wide range of parameters were sampled, including nutrients, DO, BOD, metals, salinity, and phytoplankton. The data can be retrieved from STORET, and data from 1977 and 1978 are included in the computer data set.

EPA Data--

The EPA has conducted extensive sampling programs on the Potomac since the early 1960's. The surveys include measurements of BOD, DO, nutrients, phytoplankton, salinity and temperature. The data sets collected from 1977 to 1979 (Clark and Roesch, 1978; Clark et al., 1980) are the most

TABLE 8-17. USGS SAMPLING STATIONS IN THE POTOMAC RIVER AND ESTUARY (adapted from: Blanchard and Hahl, 1981; Blanchard et al., 1982a, 1982b).

Station Number	Station Name	River Distance* (kilometer)	River Distance* (mile)	Zone
01646500	Potomac River at Little Falls, MD	189.1	117.5	River
01646580	Potomac River at Chain Chain Bridge at Washington, DC	187.2	116.3	Riverine - tidal river boundary
01647600	Potomac River at Wisconsin Ave., Washington, DC	181.7	112.9	Tidal river
385315077031800	Potomac River at Memorial Bridge, Washington, DC	179.5	111.5	Tidal river
385223077022400	Potomac River at 14th Street Bridge, Washington, DC	177.3	110.2	Tidal river
385130077014501	Potomac River at Hains Point, Washington, DC	175.3	108.9	Tidal river
385039077012600	Potomac River at Giesboro Point, Washington, DC	173.7	107.9	Tidal river
385141077015000	Potomac River at Dangerfield Island, Washington, DC	171.3	106.4	Tidal river
384852077020500	Potomac River at Marbury Point, Washington, DC	170.4	105.9	Tidal river
384815077011001	Potomac River at Blue Plains, Washington, DC	170.3	105.8	Tidal river
384852077014000	Blue Plains Sewage Treatment Plant, Washington, DC			

(Continued)

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TABLE 8-17. (Continued)

Station Number	Station Name	River Distance* (kilometer)	River Distance* (mile)	Zone
384852077014001	Blue Plains Sewage Treagment Plant, Outfall 001, Washington, DC			
384852077014002	Blue Plains Sewage Treatment Plant, Outfall 002, Washington, DC			
01652590	Potomac River at Alexandria, VA	168.0	104.4	Tidal river
384700077013001	Potomac River at Hunting Creek, VA	166.9	103.7	Tidal river
384605077015800	Potomac River at Rosier Bluff, MD	165.6	102.9	Tidal river
384318077020300	Potomac River at Hatton Point, MD	160.0	99.4	Tidal river
384136077054600	Potomac River at Marshall Hall, MD	151.0	93.8	Tidal river
383818077072800	Potomac River at Hallowing Point, VA	144.0	89.5	Tidal river
01655480	Potomac River at Indian Head, MD	138.9	86.3	Tidal river
01658710	Potomac River at Quantico, VA	125.6	78.0	Tidal river - transition boundary
38264007715990	Potomac River at Douglas Point, MD	116.7	72.5	Transition
382124077122700	Potomac River at Maryland Point, MD	103.5	64.3	Transition
382233077102000	Potomac River at Stuart Wharf, VA	98.9	61.5	Transition

(Continued)

TABLE 8-17. (Concluded)

Station Number	Station Name	River Distance* (kilometer)	River Distance* (mile)	Zone
01660800	Potomac River near Morgantown, MD	80.4	50.0	Transition - estuarine boundary
381516076503000	Potomac River at Cobb Island, MD	60.0	37.3	Estuarine
01661475	Potomac River at Piney Point, MD	29.8	18.5	Estuarine
380212076195000	Potomac River at Pt. Lookout, MD	6.5	4.0	Potomac estuary - Chesapeake Bay boundary
01661590	Potomac River at Pt. Lookout, MD			

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*The USGS gives river distances measured upstream from the confluence with Chesapeake Bay, unlike the EPA which measures distances downstream from Chain Bridge.

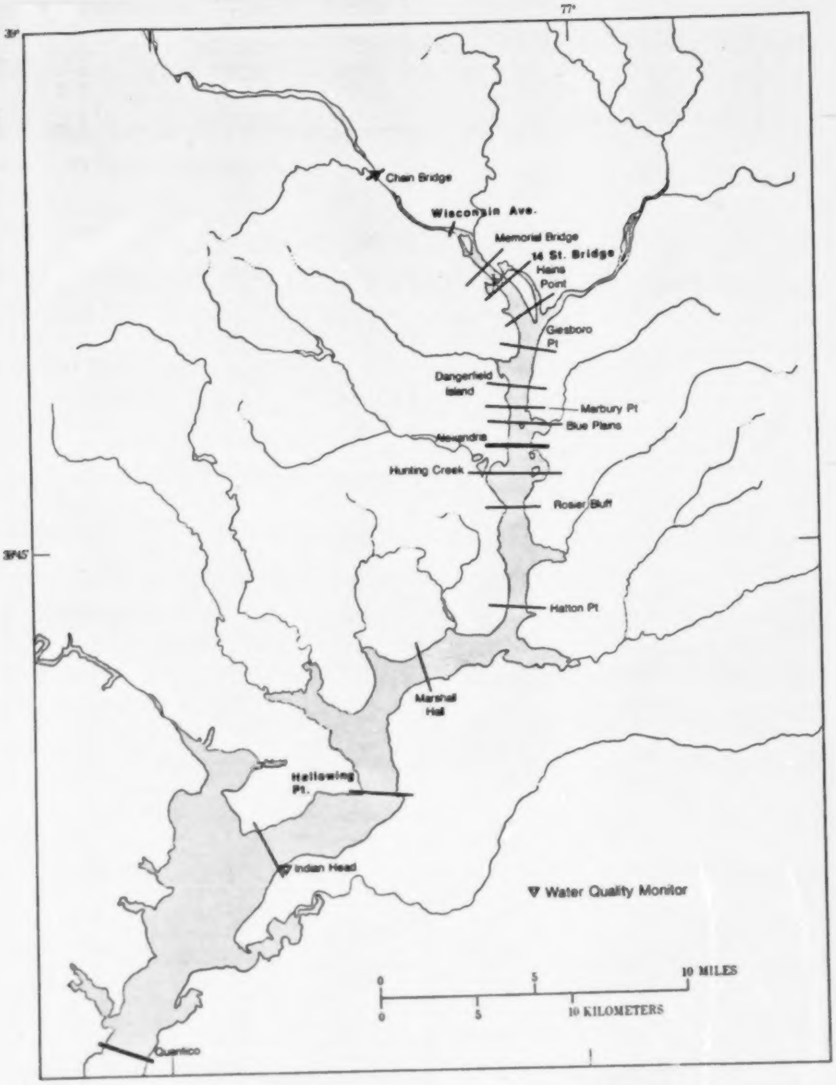
77°
39°
38°45'
Chain Bridge
Wisconsin Ave.
Memorial Bridge
14 St. Bridge
Hains Point
Giesboro Pt
Dangerfield Island
Marbury Pt
Blue Plains
Alexandria
Hunting Creek
Rosier Bluff
Hatton Pt
Marshall Hall
Hallowing Pt.
Indian Head
▼ Water Quality Monitor
0 5 10 MILES
0 5 10 KILOMETERS
Quantico

Figure 8-11a. USGS sampling stations in the Potomac River and Estuary (adapted from: Blanchard and Hahl, 1981; Blanchard et al., 1982a, 1982b). The shaded area shows the tidal river zone.

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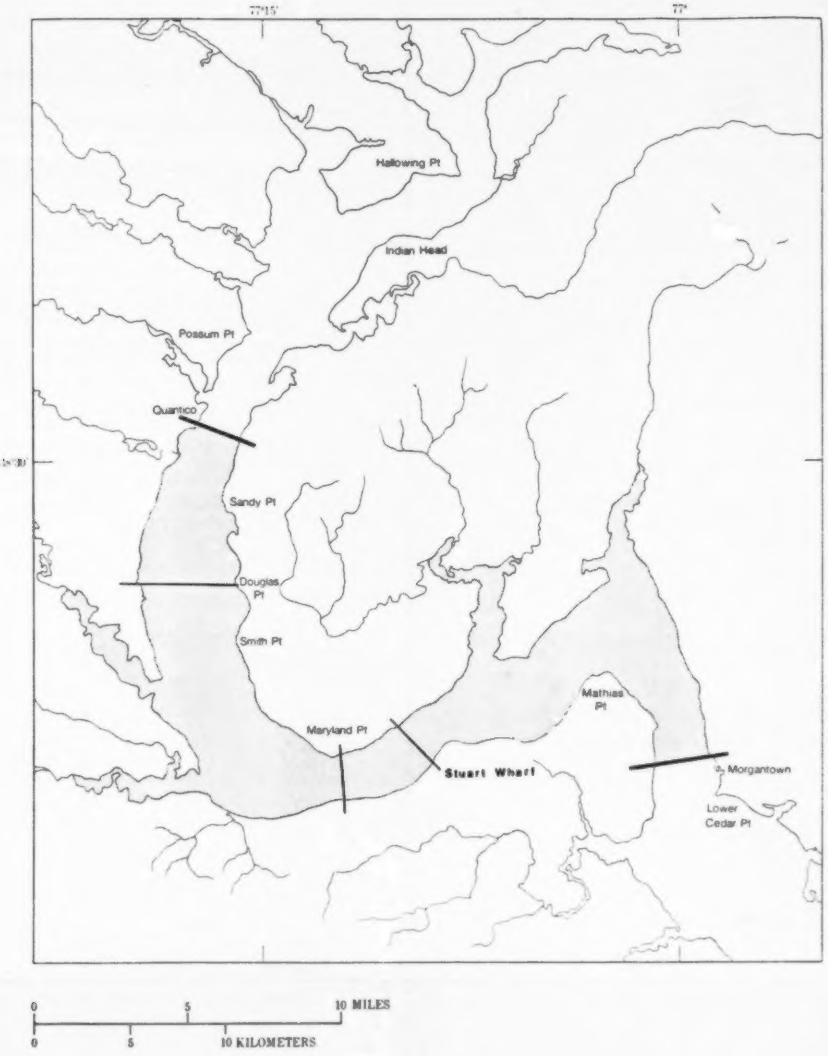
77°15'
77°
38°30'
Hallowing Pt
Indian Head
Possum Pt
Quantico
Sandy Pt
Douglas Pt
Smith Pt
Maryland Pt
Stuart Wharf
Mathias Pt
Morgantown
Lower Cedar Pt
0
5
10 MILES
0
5
10 KILOMETERS

Figure 8-11b. USGS sampling stations in the Potomac River and Estuary (adapted from: Blanchard and Hahl, 1981; Blanchard et al., 1982a, 1982b). The shaded area shows the transition zone between tidal river and estuary.

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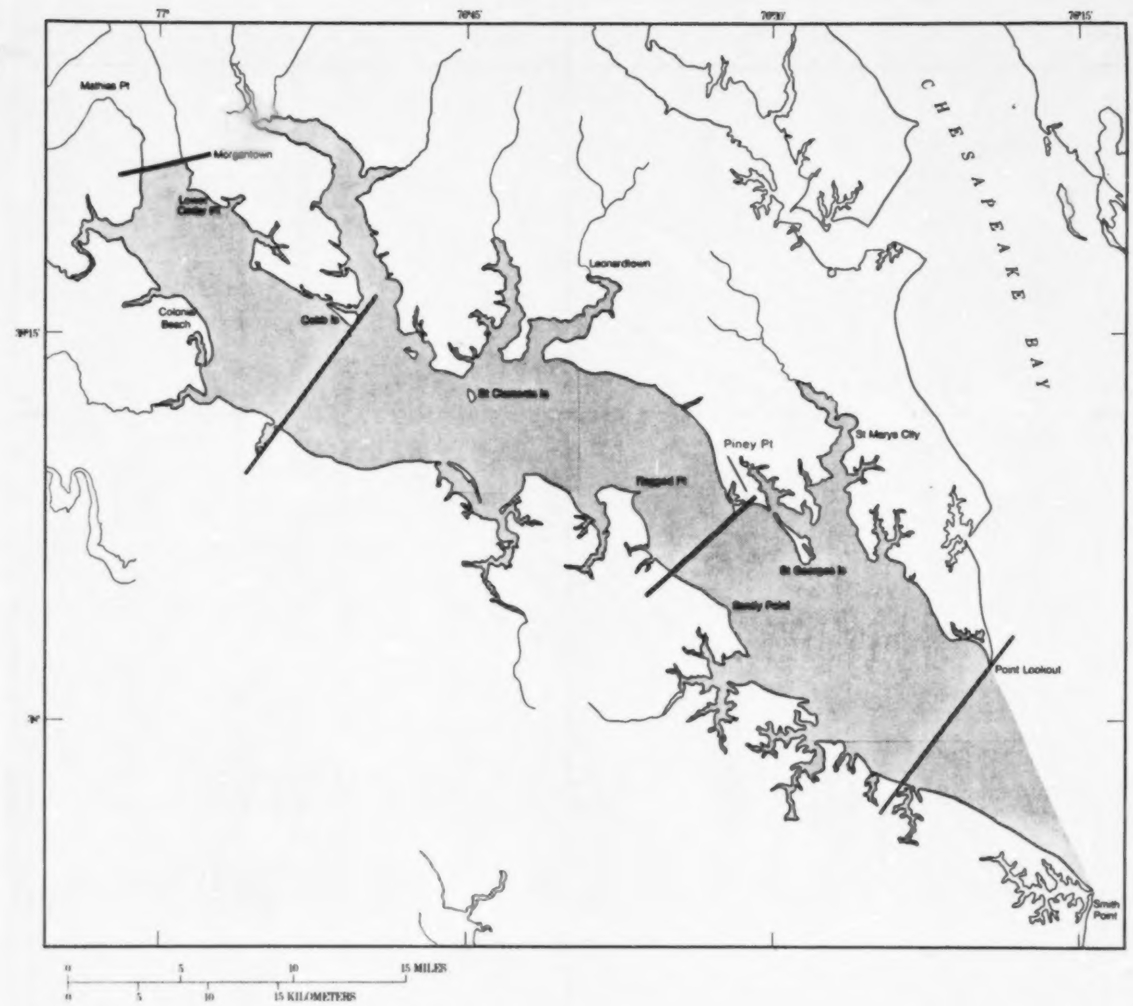
77°
76°45'
76°30'
76°15'
38°15'
38°
Mathias Pt
Morgantown
Lower Cedar Pt
Colonial Beach
Cobb Is
St Clements Is
Leonardtown
CHESAPEAKE BAY
Piney Pt
St Marys City
Ragged Pt
St Georges Is
Sandy Point
Point Lookout
Smith Point
0
5
10
15 MILES
0
5
10
15 KILOMETERS

Figure 8-11c. USGS sampling stations in the Potomac River and Estuary (adapted from: Blanchard and Hahl, 1981; Blanchard et al., 1982a, 1982b). The shaded area shows the estuarine zone.

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(PREVIOUSLY EPA FORM 257)
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TABLE 8-18. EPA SAMPLING STATIONS IN THE POTOMAC RIVER AND ESTUARY (after Thomann and Fitzpatrick, 1982, and Council of Governments data tape)

EPA Station Number	Station Name	River Distance* (mile)	River Distance* (kilometer)
P-8	Chain Bridge	0.0	0.0
P-4	Above Windy Run (opposite Georgetown Reservoir)	1.9	3.1
1	Key Bridge	3.4	5.4
1-A	Memorial Bridge	4.9	7.8
2	14th Street Bridge	5.9	9.5
3	Hains Point	7.6	12.2
4	Bellevue	10.0	16.1
	Blue Plains STP	10.4	16.7
5	Woodrow Wilson Bridge	12.1	19.5
5-A	Rosier Bluff	13.6	21.9
6	Opposite Broad Creek	15.2	24.4
7	Fort Washington (Piscataway)	18.4	29.5
8	Dogue Creek - Marshall Hall	22.3	35.9
8-A	Opposite Grunston Cove	24.3	39.1
9	Chapman Point - Hallowing Point	26.9	43.3
10	Indian Head	30.6	49.3
	Occoquan Bay	31.8	51.2
10-B	Deep Point - Freestone Point	34.0	54.7
11	Possum Point	38.0	61.2
12	Sandy Point	42.5	68.4
13	Smith Point	45.8	73.7
14	Maryland Point	52.4	84.3
15	Opposite Nanjemoy Creek	58.6	94.2
15-A	Mathias Point	62.8	101.1
16	Route 307 Bridge	67.4	108.5
17	Upper Machodoc	70.8	113.9
18	Kettle Bottom	76.6	123.3
19	Wicomico	82.0	132.0
20	Kingcopsico Point	90.3	145.3
21	Ragged Point	95.4	153.5
22	Piney Point	99.2	159.6
23	Point Lookout	107.4	172.8

*Distance downstream from Chain Bridge

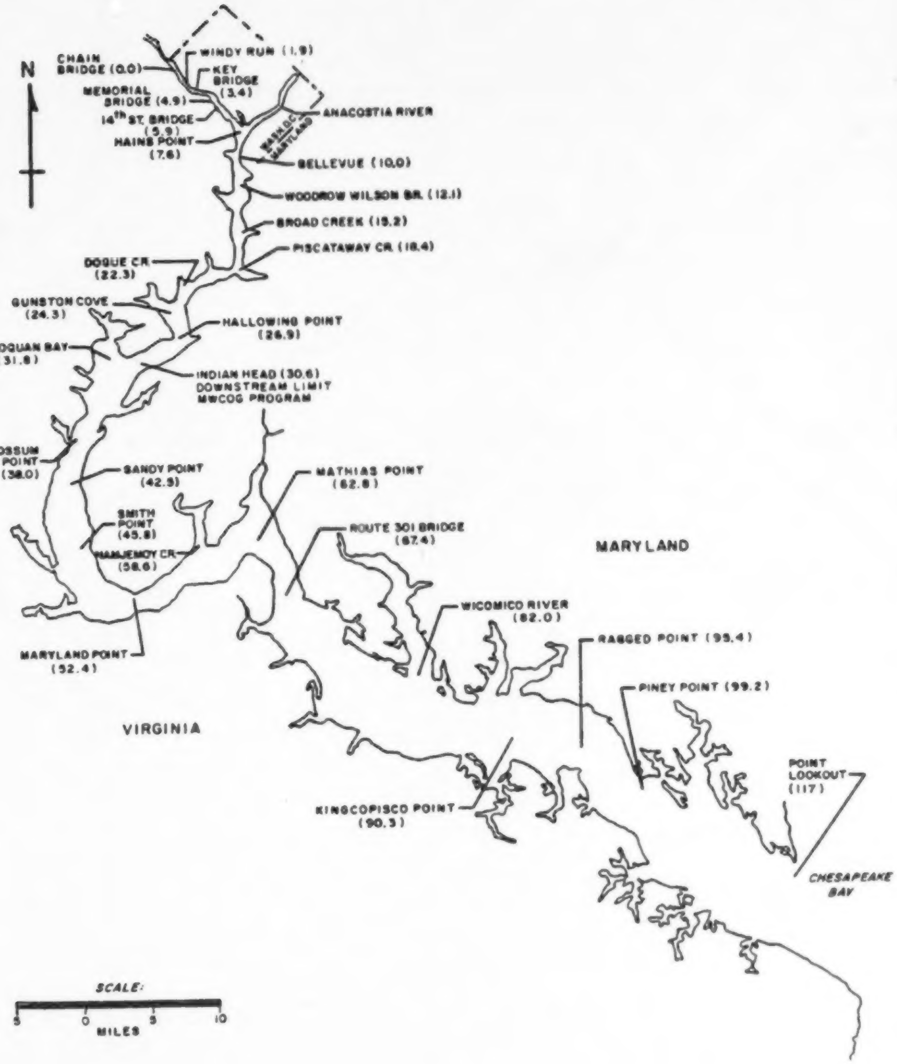
N
CHAIN BRIDGE (0.0)
WINDY RUN (1.9)
KEY BRIDGE (3.4)
MEMORIAL BRIDGE (4.9)
14th ST. BRIDGE (5.9)
HAINS POINT (7.6)
ANACOSTIA RIVER
WASH. D.C.
MARYLAND
BELLEVUE (10.0)
WOODROW WILSON BR. (12.1)
BROAD CREEK (15.2)
PISCATAWAY CR. (18.4)
DOGUE CR. (22.3)
GUNSTON COVE (24.3)
HALLOWING POINT (26.9)
OCCOQUAN BAY (31.8)
INDIAN HEAD (30.6) DOWNSTREAM LIMIT MWCOG PROGRAM
POSSUM POINT (38.0)
SANDY POINT (42.5)
MATHIAS POINT (62.8)
SMITH POINT (45.8)
MAMJEMOY CR. (58.6)
ROUTE 301 BRIDGE (67.4)
MARYLAND
WICOMICO RIVER (82.0)
RAGGED POINT (95.4)
PINEY POINT (99.2)
MARYLAND POINT (52.4)
VIRGINIA
KINGCOPISCO POINT (90.3)
POINT LOOKOUT (117)
CHESAPEAKE BAY
SCALE:
5 0 5 10
MILES

Figure 8-12. EPA sampling stations in the Potomac River and Estuary (after Thomann and Fitzpatrick, 1982).

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useful because of the higher frequency of measurements and the measurements of STP loads. The computer data set includes EPA data from 1965 to 1979.

O'Brien and Gere Data--

O'Brien and Gere Inc. have acted as consultants to the District of Columbia in evaluating the loads from CSO's and their effects on the Potomac Estuary. Unfortunately, these data are not published, and further information on the sampling programs must be sought directly from O'Brien and Gere Inc., who have supplied their data from 1979 and 1980 to the University of Florida. These data include estimates of CSO and STP loads, and water quality data from the Potomac and Anacostia Rivers with an emphasis on DO, BOD, nutrients, suspended solids, and coliforms. The river quality data are included in the computer data set, and the loading information is given in an addendum to this report.

Other Data--

Water quality data from the Potomac Estuary have also been collected by a number of other agencies such as the U.S. Army Corps of Engineers and local state environmental and pollution control agencies. Some of these data may be retrieved from STORET, and some are probably rather difficult to find in a readily useable form. The computer data set contains water quality data collected by the Corps of Engineers during 1977 and 1978. These data were supplied by the Council of Governments in a personal communication, and they may not have been published.

8-4-4. Sampling Techniques

Due to the enormous quantity of water quality information from the Potomac Estuary, and the diverse sampling efforts and agencies which produced it, it is not practical to include information on the sampling techniques which were employed. The USGS has issued a number of reports describing its data collection efforts (Cole and Alpine, 1980; Blanchard and Hahl, 1981; Blanchard et al., 1982a, 1982b). Similarly, the EPA has also issued reports on its Potomac water quality data collection programs (most recently: Clark and Roesch, 1978; Clark et al., 1980). Information on the sampling techniques used in these programs may be obtained directly from the data reports.

Information on the sampling techniques used in other data collections is often difficult to find. For instance, much of the CSO study data from O'Brien and Gere Inc. are unpublished, so that there is no readily available documentation on sampling techniques.

8-5. COMPUTER DATA SET

The computer data set contains data from a number of different sources, and in some respects the different data collections overlap. However, it is easier to keep them separate than to attempt to amalgamate them, and it is hoped that users will bear with the areas where repetition occurs.

Council of Governments Data--

The Washington, DC Council of Governments provided the University of Florida with a data tape prepared by Limnotech Inc. of Ann Arbor, MI containing data from surveys by the EPA, the USGS, and the U.S. Army Corps of Engineers. These data are summarized in Table 8-19, and some of the source documentation is described in Section 8-4-3. The USGS sampling stations are given in Table 8-17 and Figure 8-11, while those used by the EPA are given in Table 8-18 and Figure 8-12. The Corps of Engineers sampling stations are in the same positions as EPA stations in the upper part of the Potomac tidal river section.

The greatest weakness of this data set is the lack of loading data. In part this omission may be accounted for by the fact that until the mid 1970's very few loading data were collected. However, there are some earlier loading data, and Thomann and Fitzpatrick (1982) made approximations from the existing data which enabled them to use the earlier water quality data for calibration of the Potomac Eutrophication Model (PEM).

EPA Data--

The EPA Central Regional Laboratory at Annapolis (L.J. Clark, personal communication, 1982) provided a card-deck giving the data from their 1978 and 1980 reports. This data set includes tidal river and estuary water quality measurements with STP loads for the same periods. The data were measured from July through September in 1977 and 1978, and the times and dates of measurements are given in Table 8-20. Table 8-20 also contains information on precipitation and tidal conditions during the surveys, and estimated urban non-point loadings during the 1978 survey are given in Table 8-15. The sampling station positions are given in Table 8-18 and Figure 8-12, and the parameters which were measured are given in Table 8-21. A card deck of input data for the DEM model was also supplied. The data cover the O'Brien and Gere wet-weather surveys described below, and include loading data.

O'Brien and Gere Data--

O'Brien and Gere Inc. performed wet-weather surveys of the Potomac and Anacostia rivers in September 1979 and July 1980 to study the effects of CSO's on the river system. The computer data set contains water quality data from the Potomac and Anacostia rivers measured at frequent intervals from 9/21/79 to 9/28/79, and from 7/17/80 to 7/28/80. A summary of the water quality data is presented in Table 8-22, and the river sampling stations are shown in Figures 8-13 and 8-14. The STP and CSO loading data are given in an addendum to this report.

8-6. REFERENCES

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TABLE 8-19. SUMMARY OF DATA SUPPLIED BY COUNCIL OF GOVERNMENTS

Parameters Listed	Measuring Agency	Duration of Sampling	Number of Stations
Date Temperature DO BOD_5 Total-P (filtered & unfiltered) Inorganic-P (filtered & unfiltered) TKN (filtered & unfiltered) NH_3 (filtered & unfiltered) NO_3 (filtered & unfiltered) Organic-N Chlorophyll-a Secchi depth Salinity Chloride Total suspended solids Flow Depth	EPA	1965-1979	29
	U.S. Army Corps of Engineers	1977-1978	5
	USGS	1977-1978	28

TABLE 8-20. EPA INTENSIVE SURVEY DATES AND PRECIPITATION DURING SURVEYS, 1977 AND 1978

Date	Precipitation (inches)	Water Quality Sampling		Tide
		Start time	End time	
7/17/77	0.24			
7/18/77		1125	1700	LWS
7/20/77		1245	1710	LWS
7/21/77	0.59			
7/25/77	0.30	1100	1505	HWS
7/27/77		0855	1410	LWS
8/01/77	1.08	1145	1610	LWS
8/03/77		0830	1301	HWS
8/05/77	0.33			
8/14/77	1.20			
8/22/77		1035	1540	HWS
8/24/77	1.23	1130	1535	HWS
8/29/77		1055	1512	*
8/30/77	0.40			
8/31/77		0910	1313	HWS
9/06/77		1245	1700	HWS
9/08/77		0930	1335	LWS
7/17/78		0900	1340	LWS
7/19/78		1050	1545	LWS
7/30/78	0.35			
7/31/78	0.85			
8/01/78		1200	1500	LWS
8/03/78		1040	1520	LWS**
8/04/78	0.50			
8/05/78	0.45			
8/09/78	0.30			
8/11/78	0.60			
8/13/78	1.20			
8/14/78		1140	1615	HWS**
8/16/78		0940	1450	LWS
8/27/78	0.35			
8/28/78		1230	1650	HWS**
8/30/78	2.00	1120	1400	LWS
9/05/78		0900	1100	HWS
9/11/78		1045	1525	HWS
9/12/78	0.55			
9/13/78		0800	1240	LWS
9/22/78	0.25			
9/25/78		1045	1500	HWS
9/27/78		0850	1520	-

*Missed LWS

**Slightly ahead of slack tide

TABLE 8-21. PARAMETERS MEASURED IN INTENSIVE EPA SURVEYS, 1977 and 1978

Year	Estuary Water Parameters		STP Effluent Parameters
	Streamflow	pH	Flow
	Salinity	Temperature	Total C
	Secchi depth	Turbidity	Total organic C
	DO	Chlorophyll *a*	Total PO_4
1977	Total C	Total organic C	Inorganic PO_4
	NO_2-NO_3	NH_3	TKN
	BOD_5	BOD_{20}	NO_3-NO_3
	Total PO_4 (filtered & unfiltered)		NH_3
	Inorganic PO_4 (filtered & unfiltered)		BOD_5
	TKN (filtered & unfiltered)		Turbidity
	Streamflow	pH	Flow
	Conductivity	Salinity	Total organic C (filtered & unfiltered)
	Temperature	Secchi depth	
	DO (surface)	DO (5' depth)	Total PO_4 (filtered & unfiltered)
1978	Chlorophyll *a*	Turbidity	
	NO_2-NO_3	NH_3	Inorganic PO_4
	BOD_5	BOD_{20}	TKN (filtered & unfiltered)
	Inorganic PO_4		
	Total organic C (filtered & unfiltered)		NO_2-NO_3
	Total PO_4 (filtered & unfiltered)		NH_3
	TKN (filtered & unfiltered)		Turbidity

TABLE 8-22. SUMMARY OF O'BRIEN AND GERE WET-WEATHER SURVEY DATA, 1979 and 1980

Survey Duration	Days on which rain fell	River and Estuary Water Quality Parameters Measured*
9/21/79 to 9/28/79	9/21/79	BOD_5 (filtered & unfiltered), BOD_{10} (filtered & unfiltered), BOD_2 (filtered & unfiltered), BOD_{20} (filtered and unfiltered), chlorophyll, DO, Fecal coliform and streptococcus, NH_3-N, NO_2-NO_3-N, ortho-P
7/17/80 to 7/28/80	7/16/80 7/17/80 7/21/80 7/22/80	

*Not all parameters were measured at all stations and sampling times.

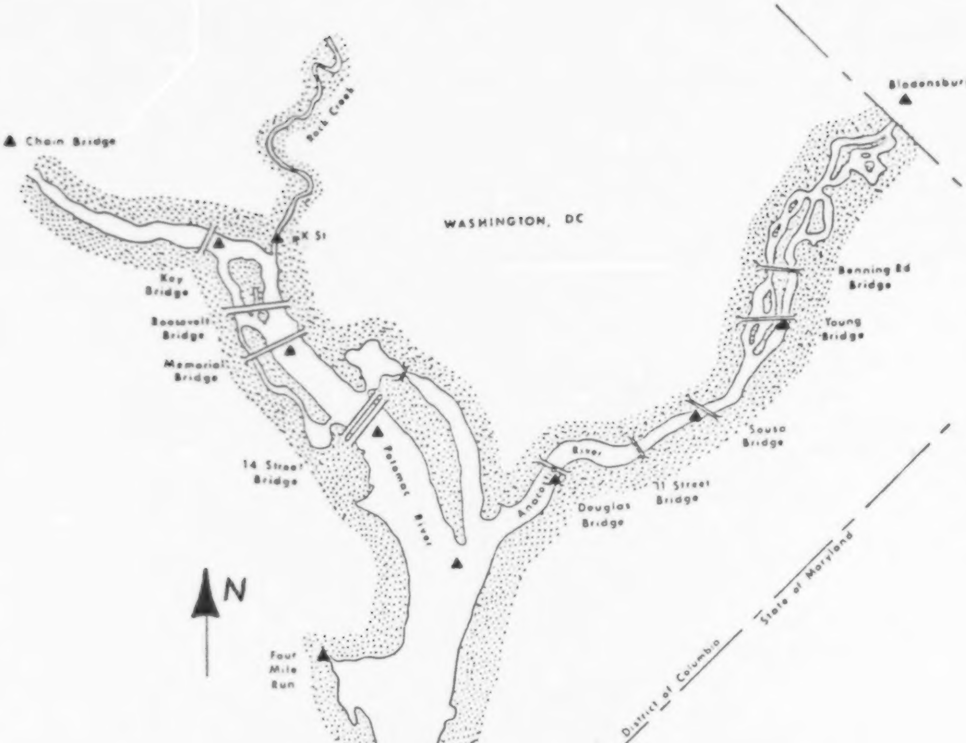
Chain Bridge
Rock Creek
WASHINGTON, DC
K St
Key Bridge
Roosevelt Bridge
Memorial Bridge
14 Street Bridge
Potomac River
Anacostia River
Douglas Bridge
11 Street Bridge
Sousa Bridge
Young Bridge
Benning Rd Bridge
Bladensburg
N
Four Mile Run
Blue Plains
Wilson Bridge
District of Columbia
State of Maryland

Figure 8-13. O'Brien and Gere sampling stations in the Potomac and Anacostia Rivers (after O'Brien and Gere, unpublished).

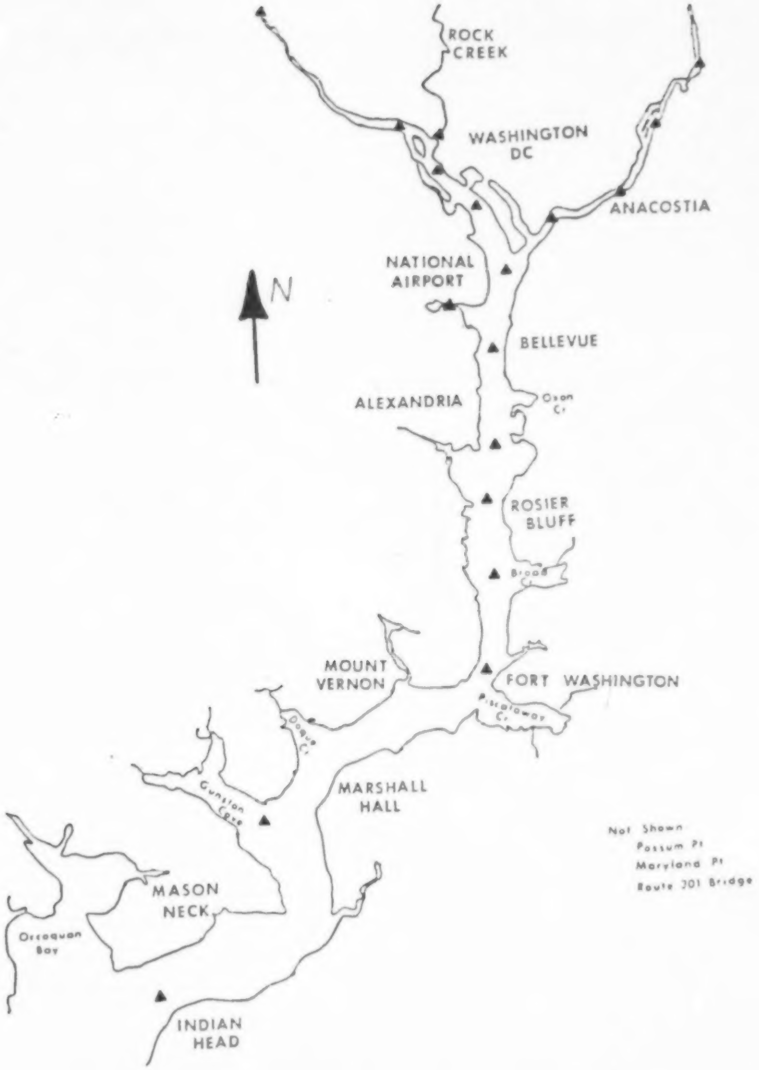
ROCK CREEK
WASHINGTON DC
ANACOSTIA
N
NATIONAL AIRPORT
BELLEVUE
ALEXANDRIA
Oxon Cr
ROSIER BLUFF
Broad Cr
MOUNT VERNON
FORT WASHINGTON
Piscataway Cr.
Dogue Cr.
MARSHALL HALL
Gunston Cove
Not Shown:
Possum Pt
Maryland Pt
Route 301 Bridge
MASON NECK
Occoquan Bay
INDIAN HEAD

Figure 8-14. O'Brien and Gere sampling stations in the upper Potomac Estuary (after O'Brien and Gere, unpublished).

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SECTION 9

ADDITIONAL DATA SITES

9-1. INTRODUCTION

Many potential locations were reviewed, but time and resources required for processing the information resulted in limiting the sites included in this report to only seven. Several other locations could provide additional data; seven are discussed below. Considerable information was gathered for these sites as part of this project, but they could not be included because key information was missing, voluminous data were not computerized or transferable, the study was not completed, or time and resources were insufficient to process all the information. Several other potential locations are not discussed herein, but the reader should be aware that many such locations exist, particularly for rivers and streams. A good information source is often a state "environmental protection" agency since its personnel will often be aware of modelling studies within a state. The paragraphs that follow discuss only seven sites that were extensively investigated as part of this project. These are also indicated in Figure 1-1.

9-2. RIVERS

9-2-1. Willamette River, Oregon

The Willamette River is about 250 mi (400 km) long and flows northward in western Oregon through Eugene and Salem to its junction with the Columbia River at Portland. The lower 187 mi (300 km) was the location of an intensive USGS river quality assessment during 1973-74 (Greeson et al., 1977). Other river quality assessments have been performed for the Chattahoochee River, Georgia (see Section 4) and for the Yampa Basin in Colorado and Wyoming. The Willamette study emphasized DO problems, but also included data algal dynamics, trace metals and impacts of erosion.

The USGS has provided extensive documentation of the assessment in its series of Circulars, 715 A-M, and Ancillary studies also exist, e.g., Huff et al. (1976), Klingeman (1979), Spycher et al. (1980). Although McCutcheon (1982) was able to obtain sufficient data to perform modelling studies, UF was never able to obtain the raw water quality sampling data. For instance, the Circulars present only results of various analyses. Eventually the data should be retrievable from the EPA STORET database.

9-2-2. Arkansas River, Colorado

The USGS has engaged in data collection and modelling activities on a 42 mi (67 km) stretch of the Arkansas River downstream from Pueblo, Colorado. Intensive surveys were conducted April 1-2, 1976, October 12-14, 1976 and September 17-20, 1979. The 1976 surveys are described by Goddard (1980) while the 1979 survey is described by Cain and Edleman (1980) and Cain et al. (1980). The main purpose of the data collection and modelling was a waste assimilation study (Cain et al., 1980).

Data for DO, nutrients and a few other parameters were collected in addition to flow and temperature. The data were also used by McCutcheon (1982) for model testing. The location is not included in this report because four other river sites had already been documented.

9-2-3. Ouachita River, Louisiana and Arkansas

In an effort to test various one-dimensional water quality models, four intensive data collection surveys were conducted by the National Council of the Paper Industry for Air and Stream Improvement (NCASI) on the lower Ouachita River in 1980 (Whittemore and Hovis, 1982a). The NCASI also conducted reaeration studies on the river (Whittemore and Hovis, 1982b, Whittemore, 1982), and the river was studied additionally as part of the EPA 208 program and by the State of Louisiana and the USGS in Little Rock. Emphasis was upon DO, BOD and nitrogen data.

Much of the lower Ouachita River is in the form of dams and pools and as such is sluggish and subject to DO stratification. Additionally, there appear to be algal effects which were not entirely quantified in the studies. Nonetheless, four models (similar to QUAL-II) were successfully calibrated, and the report (Whittemore and Hovis, 1982a) documents the extentive efforts at parameter estimation. The location was not included as part of this report because the documentation arrived too late during the project, and because the four other river sites appeared to be somewhat more straightforward from a modelling viewpoint.

9-2-4. Others

As has been stated previously, river and stream data are so plentiful that no additional potential sources are listed here.

9-3. LAKES

9-3-1. Lake George, New York

Lake George in northeastern New York is one of the most studied lakes in the Northeast, and has been sampled intensively by the Fresh Water Institute and the Center for Ecological Modeling at Rensselaer Polytechnic Institute (RPI), especially as part of the International Biological Program (IBP) during 1969-74. Monitoring has continued since 1974 under various programs, including a recent study of the southern portion of the lake as part of the EPA Nationwide Urban Runoff Program (NURP). The 114 km^2 (44 mi^2) lake is relatively deep, with a maximum depth of 58 m (191 ft) and an average depth of 18 m (59 ft), and is subject to thermal stratification in the summer and ice cover in the winter. It is renowned for its clarity and experiences a large seasonal population influx in the summer. It is also used as a water supply by all lake communities. A summary of lake characteristics is given by Ferris and Clesceri (1977).

Various eutrophication models have been applied to the oligotrohpic lake (Ferris and Clesceri, 1977), and the aquatic ecosystem model CLEANER was first tested there (Park et al., 1975). Recent work by RPI, EPA and the New York State Department of Environmental Conservation (DEC) has tended to emphasize nutrient budgets and the impact of point and non-point source runoff into the lake, e.g., Aulenbach et al. (1980), Siegfried (1982). Both of these references contain useful literature reviews.

The main problem with Lake George as a location for this project is that its vast data assemblage is generally not computerized. Furthermore, keypunching of the printed values of raw data would apparently require the coordination of RPI personnel to obtain a meaningful database. Although recent NURP data will eventually be available from STORET, the status of the IBP and other earlier data remains uncertain in terms of transferability.

9-3-2. Onondaga Lake, New York

Located in Syracuse, New York, 4.6 mi^2 (11.9 km^2) Onondoga Lake receives inflows from the Syracuse sewage treatment plant, industries, streams, combined sewer overflows (CSO's) and storm sewers. The eutrophic lake is dimictic (mixes completely twice a year) and has average and maximum depths of 39 ft (12 m) and 67 ft (20 m), respectively. It has been studied extensively since 1969, with the ultimate objective of restoration to a less eutrophic condition. Effler et al. (1981) describe the progress of these lake restoration efforts and discuss general lake characteristics with emphasis upon its trophic state. A significant aspect of the EPA-sponsored studies was the effect of various source controls, in particular control of CSO's. The CSO studies were related to other EPA demonstration projects in Syracuse (e.g., Drehwing et al., 1979); CSO impacts on the lake are described by Moffa et al. (1980). These impacts were evaluated through the use of a 27 segment, two-layer transient finite difference model developed by Freedman et al. (1980) specifically for Onondaga Lake. The model was applied to DO, including nutrients and algal dynamics, and to bacteria. It was calibrated against four wet-weather data surveys in 1975 and annual average data for 1975 (incorporating long term samples).

The lake circulation is complex and exhibits two distinct gyres during part of the year. The stratification is also affected by high chloride concentrations of 1250 and 1500 mg/l in the epiliminion and hypolimnion, respectively (Effler et al., 1981). Although the 1975 data have been computerized by Freedman et al. (1980), the problems with accurately defining the lake circulation militated against inclusion of Onondaga Lake in this report.

9-3-3. Others

Many lake quality studies are cited in the limnetic literature, some with sufficient detail for modelling. Examples of well-studied lakes include Lakes Ontario and Erie, Lake Washington at Seattle, Lakes Wingra and Mendota at Madison, Wisconsin, and Lake Apopka near Orlando, Florida, all of which are amply cited in the literature. Reservoir quality data have also been gathered by the Tennessee Valley Authority and by the Corps of Engineers, Waterways Experiment Station.

9-4. ESTUARIES/BAYS

9-4-1. Delaware Estuary

With the Potomac, the Delaware is probably one of the two most studied estuaries in the country. The 86 mi (138 km) stretch from the head of tide at Trenton, NJ to Liston Point, DE on Delaware Bay has been the focus of many studies since the early 1960's. The lower portion of the estuary is heavily used by commerce and flows past the metropolitan Philadelphia area from which it receives large point and non-point inflows. Increased treatment of point sources in the 1970's has tended to raise DO levels that were observed to be as low as 1 mg/l downstream of Philadelphia during the 1960's. A good summary of earlier studies on the estuary is given by Thomann (1972), including a discussion of the 1961-67 Delaware Estuary Comprehensive Study. Thomann (1972), Pence et al. (1968), Ward and Espey (1971) and O'Connor et al. (1968, 1976) also present examples of some of the earlier modelling efforts performed on the Delaware Estuary. In fact there are so many and varied data from the estuary that it has been used as a case study in numerous references. For instance, the EPA has applied the Dynamic Estuary Model (DEM) to the Delaware (Clark et al., 1978, Ambrose and Roesch, 1982), and the MIT unsteady estuary model has been applied by Najarian et al. (1980) and Thatcher and Harleman (1972, 1981) for the prediction of salinity distributions. Recent bathymetric and other modelling data may be found as part of these studies. The upper Delaware River Basin has also been studied, e.g., Brezina et al. (1976), Hull (1978).

Water quality data have been collected by several agencies, including EPA (at their Annapolis Field Office), the Delaware River Basin Commission (DRBC at Trenton, NJ), USGS, City of Philadelphia, Corps of Engineers, Chesapeake Bay Institute (Johns Hopkins University), and the bordering states of New Jersey, Pennsylvania and Delaware. Most of the recent estuary data have been published by the DRBC (e.g., DRBC, 1976) and are included in the STORET system; station ID's are available from the DRBC. The biggest problem in using the wealth of Delaware Estuary data is in colating data from different sources, including loading estimates, and reconciling the different time scales and sampling strategies. Use of data within the past decade is preferable if only because the personnel involved in those studies may still be contacted.

9-4-2. San Francisco Bay

Another location with a long heritage of study and modelling is 435 mi^2 (1130 km^2) San Francisco Bay (including San Pablo Bay in the north). The North Bay area (i.e., north of the Golden Gate) receives most of the fresh water inflow and is only partly mixed during the wet winter months, while the South Bay is usually isohaline throughout the year. The bay has a complex bottom topography, varying from tidal flats to channels up to 50 ft (15 m) in depth in the South Bay (deeper near the Golden Gate). Ocean exchange is critical in the assessment of waste assimilative capacity; "effective exchange" (bay volume replaced by "unpolluted" ocean water) is about 6% of the approximately 210×10^9 ft^3 (5.9×10^9 m^3) volume of the bay, per semi-diurnal tidal cycle (Metcalf and Eddy and Resource Management Assoc., 1978). Water quality in San Francisco Bay has improved steadily since the 1950's due to the treatment of municipal and industrial wastes and the gradual implementation of limited non-point source runoff controls -- notably for CSO control in San Francisco (summary by McPherson, 1974). In addition to pollution control, intense interest in the bay has resulted from projected alterations in the Sacramento-San Joaquin River delta area in the North Bay.

San Francisco Bay has given birth to a number of models, including the Dynamic Estuary Model (Feigner and Harris, 1970) and its derivatives (e.g., RECEIVE), Fischer's (1970) lagrangian model, and recent finite element models developed by the USGS (Walters and Cheng, 1979, 1980; Cheng, 1981). A large physical model of the bay, operated by the Corps of Engineers in Sausalito, is intensively used; an example application is given by Fischer et al. (1970). Ward and Espey (1971) discuss both physical and numerical modelling of the bay. Surface runoff into the bay has received much attention as part of EPA Section 208 and other programs (M&E and RMA, 1978, Litwin et al., 1981), including receiving water effects. Surface runoff monitoring has also been conducted by the Corps of Engineers (e.g., Hydrologic Engineering Center, 1976).

A cooperative, long-term study was begun in 1969 by the USGS at Menlo Park, California, and continues at the time of this writing. Chemical, biological and physical data have been gathered, usually during cruises at intervals of a few weeks, and are documented in open-file reports, e.g., Smith et al. (1979), Smith and Herndon (1980), Alpine et al. (1981), Gartner and Cheng (1981). Significantly, almost all data have been computerized and are stored on many magnetic tapes. An enormous amount of data from several fixed current meters from a combined 1979-80 USGS - National Ocean Survey (NOS) study will eventually be archived on magnetic tapes by the NOS.

Data since 1977 appear to be some of the most comprehensive available for two-dimensional model testing, including hydrodynamic models. Although computerized, the massive data set is not easily transferable at present; however, plans are that it will be in the future.

9-4-3. Others

A major EPA study of Chesapeake Bay is nearing completion, including detailed hydrodynamic and water quality modelling. Primary responsibility resides with the EPA Annapolis, Maryland office. The James River tributary to the bay may be seen frequently in the literature as a test case for models.

Tampa Bay has been sampled and modelled under several studies involving the USGS, University of South Florida (both at Tampa) and others. A large number of reports is available, although estimation of non-point source runoff into the bay is difficult. Recent studies are still underway.

Other east coast estuaries/bays with known quantity and quality data include the following: Manasquan Estuary, New Jersey, studied by the Manasquan River Regional Sewerage Authority (Freehold, NJ); Baranegut Bay studied by the New Jersey Department of Environmental Protection (Trenton); Naragansett Bay, studied by the University of Rhode Island; Boston Harbor, studied by the Metropolitan Sewer District and others; Jamaica Bay, Long Island, New York, studied by the city and the location of early two-dimensional model development by the Rand Corporation. As for all receiving water types, citations to these and many other locations may be found in the literature.

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